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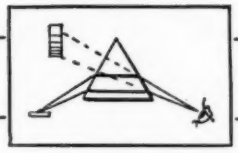

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Spectral Distribution of Radiation from Three Reflector Units

B. T. BARNES, *Incandescent Lamp Department, General Electric Company, Cleveland, Ohio*
(Received March 28, 1935)

DATA on the spectral distribution of the ultraviolet radiation from sunlamps with Type S–1 and Type S–2 Mazda lamps have already been published.[1] The present paper gives the spectral distribution of the energy radiated in the wavelength range from 2950 to 27,000A for these two sunlamps and also for a General Electric infrared unit.

Spectral intensities on the axis of each reflector at a distance of 30″ from the light center were determined with the aid of our quartz double monochromator.[2] A negative lens placed at a suitable distance in front of the entrance slit increased the effective aperture of the collimator so that radiation from all parts of the reflector passed through the monochromator. The energy passing through the exit slit was measured with either a thermopile or a calibrated photoelectric tube. The corrections for losses in the monochromator and for the effect of the negative lens used in front of the collimator were made.

Since the spectral distribution of the energy radiated from the S–1 and S–2 units depends on the tilt of the reflector, the latter was mounted at an angle at which applicator units are commonly used (axis 30° from vertical). Radiation proceeding along the reflector axis was reflected along the collimator axis of the monochromator by means of a plane mirror coated with an aluminum alloy. With the aid of a 500-watt Mazda CX lamp, the reflection factor of this mirror was determined at a number of wavelengths throughout the range covered.

The distribution of intensity about each reflector was determined with the aid of a photoelectric tube. These data were used to compute, from the measured axial intensities, the amount of energy of each wavelength falling within 20° of the axis of the reflector. These results were then reduced to percentages of the input wattage in order to make them directly comparable.

Curve *A* of Fig. 1 shows the spectral distribution of the radiation from a General Electric infrared unit with a standard 250-watt Mazda CX lamp in it. Approximate values of axial intensities, in milliwatts per square centimeter per 50A, at a distance of 30″ from the light center may be obtained by multiplying the percentages read from the curve of Fig. 1 by 3.55. (This factor is correct for λ10,000A. The factor varies slightly with wavelength because of variations in the transmission of the lamp bulb and in the reflectivity of the reflector surface.) The original data for this curve were obtained by using three lamps taken at random from regular factory production. The total luminous output from each of these lamps was

[1] W. E. Forsythe, B. T. Barnes and M. A. Easley J. Opt. Soc. Am. **24**, 178 (1934).

[2] W. E. Forsythe and B. T. Barnes Rev. Sci. Inst. **4**, 289 (1933).

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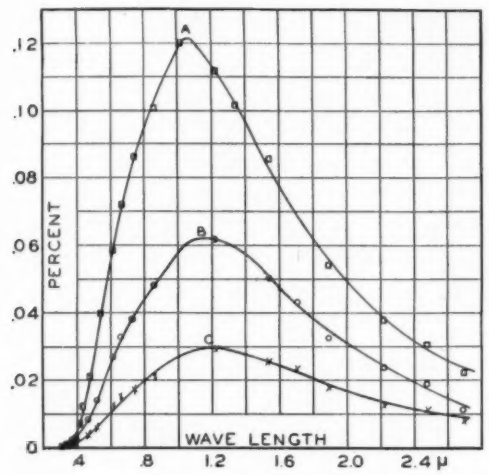

FIG. 1. Percent of input radiated in spectral band 50A wide and falling within 20° of axis at distance of 30″ from light center. *A* infrared unit, *B*, S–1 unit and *C*, S–2 unit.

determined in the Nela Park Testing Section. Dr. W. E. Forsythe of this laboratory then computed the small corrections required to reduce the results to those which would be given by a lamp operating at exactly the standard wattage and luminous efficiency for this type.

The distribution of the energy radiated in the continuous spectrum from S–1 and S–2 sunlamps is shown by curves *B* and *C* of Fig. 1. The radiation from these units in each of the principal lines of the arc spectrum is given as percentage of the input in Table I.

The data in the figure and in Table I were obtained with reflectors found by test to give approximately the same distribution of intensity as the average applicator unit sold by the General Electric Company. The S–1 data are the averages for two lots of six lamps and the S–2 the averages for three lots of three lamps obtained from the factory at various times. Since the lamps were taken at random from factory production, they should be fairly representative. Intensities on the axis of the reflector (milliwatts per cm² 30″ from center of arc) may be obtained from the percentages given in Fig. 1 and Table I by multiplying by 3.07 in the case of the S–1 unit and by 0.95 for the S–2.

The input voltage and wattage at which these units were operated and their efficiencies as sources of penetrating infrared, visible and ultraviolet radiation are given in Table II. The units were operated at the voltages at which they might be expected to operate if the open circuit line voltage were 115 volts and if the line drop were such as commonly found in the wiring in a residence.

TABLE I. *Percentage of input into primary of transformer radiated in a given spectral line and falling within 20° of reflector axis at distance of 30″ from light center.* Axis of reflector 30° from vertical.

Unit	λ13570–673	10140	5770–91	5461	4358A
S–1	.024	.022	.085	.091	.093
S–2	.015	.013	.044	.055	.050

Unit	λ4047	3650–63	3341	3126–32	3021–7	2967A
S–1	.055	.138	.0075	.064	.0146	.0062
S–2	.030	.071	.0047	.038	.0105	.0051

TABLE II. *Efficiency of units as sources of infrared, visible and ultraviolet radiation, given as energy flux per watt input within 20° of axis at distance of 30″ from light center.*

Unit	Line Volts	Amp.	Overall Watts	Penetrating* Infrared per Watt	Lumens per Watt	Erythemal† Ultraviolet per Watt
Infrared	114	2.16	246	23.4	6.2	0.6
S–1	110	10.1	451	11.8	3.6	16.5
S–2	113	3.03	149	5.4	1.8	12.6

* Milliwatts per watt input able to penetrate 5 mm through human flesh. Computed using Cartwright's transmission data, J. Opt. Soc. Am. 20, 81 (1930). The transmission through 5 mm of flesh has a maximum value of 20 percent for radiation of wavelength 11,000A and is negligible for wavelengths shorter than 5000 or longer than 16,000A.

† *E* vitons per watt input. (One *E* viton is equivalent to 10 microwatts of λ2967A in the production of a "minimum perceptible" erythema.)

The data in Table II show that the sunlamps using the Type S–1 and the Type S–2 lamps furnish considerable penetrating infrared radiation. However, they are designed primarily for supplying ultraviolet. The infrared applicator with a 250 watt Mazda CX lamp in it makes a much more suitable source both of penetrating infrared and of visible radiation.

Automatic Measurement, Reduction and Recording of Wavelengths from Spectrograms

GEORGE R. HARRISON, *George Eastman Laboratory of Physics, Massachusetts Institute of Technology*

(Received March 28, 1935)

A device is described which can be attached to any standard moving-plate comparator which automatically records the passage of the density maximum of a spectrum line, computes the wavelength corresponding to this maximum and records this value to eight figures photographically at high speed. The automatic recording, computing and measuring features can be used independently if desired. The comparator screw can be driven by hand, or by electric motor at controllable speed, through a shaft which is coupled to a wavelength shaft by means of variable ratio gears and a differential so that the speed ratio of the shafts can be rapidly adjusted to any desired instantaneous value. When measuring a plate the operator sees on a screen before him a magnified image of a portion of the spectrum; the light in this image actuates an amplifier system through three photo-cells to give records of plate density and rate of change of density with distance. When the density slope becomes zero while the density is greater than some predetermined background value a mercury arc flashes to record the wavelength dial readings. Correct wavelength readings for any desired number of standard lines can be set into the machine, or an empirical dispersion formula can be introduced. Errors due to backlash, oil film variation and temperature variation of the screw are practically eliminated, and automatic setting on most lines is found to be more accurate than hand setting. A microphotometer trace is superposed by the machine on the wavelength list so that the intensities and physical characteristics of lines can be determined directly. A ten to 200-fold gain in speed of measurement of complex spectrograms results from use of the machine. When used as a microphotometer the instrument is faster than those in common use.

§1. INTRODUCTION

RECENT attempts at analysis of very complex spectra have emphasized the need for more accurate wavelength determinations in many elements. By using ordinary methods of measurement and reduction, this would be a formidable task with atoms of the rare earth type in whose spectra ten or more lines are not infrequently found within a range of one Angstrom unit. It seemed desirable therefore to investigate the possibility of developing more rapid and more accurate methods of spectrogram measurement and reduction.

The standard wavelength comparator is commonly used in almost the same form in which it has existed for many years. The routine procedure of measuring a spectrogram consists of a series of hand and eye operations which are very fatiguing for an inexperienced worker; usually the eye must be focused through one or more eyepieces and then on scale, dial and vernier, on which the marks are often mere unfilled engraving in metal; then a six to eight digit number must be recorded manually, together with an intensity estimate for the line. The rate at which comparator settings, readings, and recordings can be made in this way varies from 60 lines per hour for the average student assistant to around 200 lines per hour for an experienced operator, over a seven hour day.

The comparator readings must next be converted into wavelengths. This operation usually requires at least twice as long as the taking of the measurements themselves, and 30 hours appears to represent a fair average figure for the total time required to obtain the final wavelengths of a thousand lines.

In the reduction of grating spectrograms, in which approximately linear dispersion is found over fairly broad ranges, it is customary to measure the displacement l of unknown and known lines (usually iron secondary and tertiary standards) relative to some known line. Approximate wavelength values λ_e are then determined for all lines by using a linear dispersion for the whole plate or such part of it as can be measured with a single disposition of the plate on the comparator. A correction curve is next plotted for the standard lines of known wavelength λ, with $\lambda_e-\lambda$ as ordinates and l or λ_e values as abscissas. The proper correction $\lambda-\lambda_e$ to be applied to each λ_e of an unknown line is then read from this curve. Even when using an electric calculating machine this procedure is lengthy and involves much recording of purely

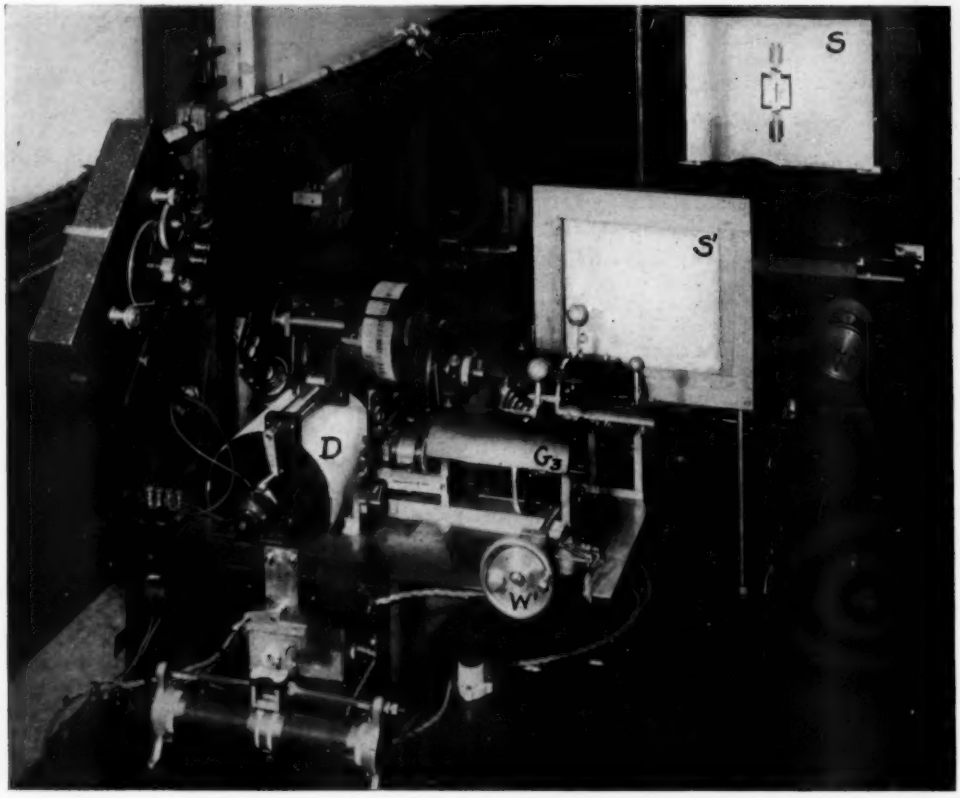

FIG 1. View of the reducing and recording machine and the comparator belted together. An image of the spectrogram is projected on the opaque screen S for automatic recording, and on ground-glass screen S' where the operator can observe it.

incidental numbers. All the operations are simple arithmetical processes which could be done mechanically and quite automatically by means of gears, with only a single recording of the final result necessary.

Considerations of this sort suggest a number of possibilities for utilizing improved apparatus which has only become available within the last few years, to diminish the labor involved in the measurement and reduction of spectrograms. A preliminary report[1] has been made of a machine constructed with this end in view; this device has been in operation for over a year, and has been modified and improved, while the feature of high speed automatic line setting has been added.

The complete outfit is depicted in Fig. 1. It consists of a 40-cm Societé Genevoise moving plate comparator with an a.c. amplifier projection microphotometer[2] incorporated, belted by means of a perforated steel tape to the reducing and recording machine. The operator sits in front of the machine and has complete control of the comparator with hand or variable speed motor operation. The comparator can be operated in the ordinary way, or hand setting on lines with automatic reduction to final wavelength values can be used; photographic recording of the results is available if desired; finally, automatic determination of line centers can be combined with these features, and the machine

[1] G. R. Harrison, Phys. Rev. **45**, 760 (1934).

[2] G. R. Harrison, J. Opt. Soc. Am. **19**, 301 (1929).

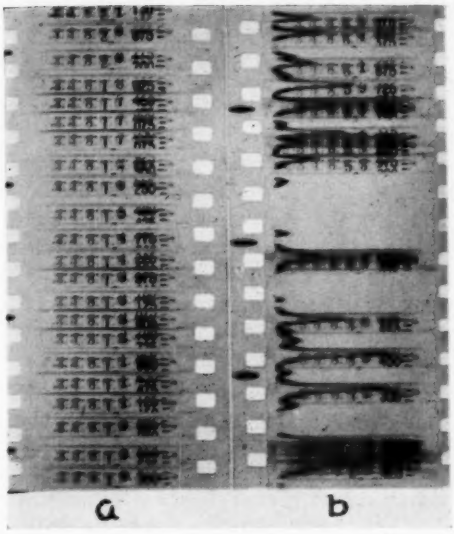

FIG. 2. (a) Portion of a wavelength record with uniform spacing and with intensity marks omitted; (b) Portion of a wavelength record with spacing proportional to wavelength, with a simultaneously recorded density curve. The recording camera was here driven with the middle speed of three provided from the wavelength shaft S'' of Fig. 3. The recorder was set to give medium and strong lines only.

can be set running to issue a list of final wavelength values to seven or eight figures, on which is superposed a microphotometer trace of the spectrum measured, as shown in Fig. 2b. The entire device or any one of its features can be added to an ordinary comparator with a great saving in the time required for wavelength measurements.

Automatic measurement, reduction and recording will be discussed independently and in reverse order, since this corresponds to the order of the convenience of their application to a standard moving plate comparator.

§2. Rapid Recording of Comparator Readings

It has been found in this laboratory that at least two-thirds of the time required to measure a spectrum plate in the ordinary way is occupied in recording the comparator readings. To expedite this is of importance, not only for the time saved, but for the increase in accuracy and convenience resulting if an entire plate can be measured at a single sitting rather than over several days. A number of comparators have been built provided with recording attachments whereby the operator could, by pressing a key or lever, record the screw settings to the desired number of figures and record an intensity estimate.[3] Raised numbers were provided on all dials, and a process similar to that used in typewriting caused an imprint to be made on a paper tape. Such attachments have not come into common use, apparently partly because mechanical disturbances are introduced when the printing operation is carried out.

In the device being described the recording is done photographically at small expense by using standard 35 mm positive sound recording motion picture film, which can be obtained for 1c per foot, and on a foot of which over 100 wavelength and intensity values can be recorded. A simple camera was constructed to hold 200 ft. of film at one loading, though only a few feet are needed for each plate. A Cooke *f 3.5* Anastigmat lens of two-inch focus was used to give a threefold diminished image of the dial figures. The film was arranged to be advanced 3 mm whenever an electromagnet is energized (Fig. 2a), or to be driven continuously by means of a shaft as discussed below in §3 (Fig. 2b). The exposed film can be cut off with scissors at any time and removed for development, leaving the camera still loaded and ready for use.

The large dial which gives the last three figures, and its pointer (Fig. 2) are arranged to be photographed directly, but are preceded by a five-bank counter, the last dial of which is turned one figure by each revolution of the large dial. This large dial is marked with 100 divisions, and is numbered every five divisions to insure that at least one set of figures will always appear in the field of view. It is of course necessary to obtain the type of counter which will record correctly for either direction of rotation, and one the dials of which can be individually reset to zero, although it was found desirable in the present case to fasten the two dials of highest

[3] H. Kayser, *Handbuch der Spektroskopie*, Vol. I, p. 644. Kayser says this device saved over half the time previously required for plate measurement. See also O. Lohse, Zeits. f. Inst. 30, 169 (1910).

speed rigidly to their shafts to avoid coasting under high acceleration. Fortunately with these two the zero reset feature is of no importance.

While the records shown in Fig. 2 give the final wavelength values directly in Angstroms to seven figures and can be read to eight, such a device can of course be used to give wave numbers or mm directly. A three-bank counter similar to the one described can be used to count screw turns, thus eliminating the usual linear scale. The dials and vernier can readily be painted with a hard dark varnish of the Duco type, the engravings being then filled in with a very white material such as Luminall white paint.

Recording of the dial readings is made with a single flash of a U-shaped glass mercury arc placed just above the dials, a condenser being discharged through the arc whenever a control circuit so directs, or the operator presses a key. The circuit now being used is shown in Fig. 7 in the section marked *D*. This thyratron circuit is a modification of one developed for the Edgerton stroboscope,[4] for advice regarding which I am greatly indebted to Professor Edgerton. The circuit provides a single flash of duration less than 10^{-5} sec. when the thyratron grid is tripped or the key is closed, and this flash gives a clear and intense record even at high dial speeds, when the circuit constants are as given in Fig. 7. With a simple comparator and hand setting on lines, when the dials are at rest during recording, the method of illumination can of course be greatly simplified.

It may be thought that since comparator readings must eventually be copied anyway it is of small value to have them photographed. However, time is at a premium while the comparator is in use, and copying can be better done at other times; also many of the wavelength values are never copied, only those being taken from the photographed list which are relevant to the problem in hand. Finally, when several identical spectrograms are being measured, or the same one several times, the group of photographed lists can be compared directly and only the finally averaged values copied.

[4] H. E. Edgerton and K. J. Germeshausen, Rev. Sci. Inst. **3**, 535 (1932).

§3. Automatic Reduction of Wavelength Values

The problem of designing an attachment for comparators which will give wavelength or wave number values directly for prism or grating spectrograms has been attacked by several investigators.[5] The devices they have described are lever and screw arrangements arranged so that correction formulas of the Hartmann type can be inserted to provide automatically dispersion variation between the motion of the plate carriage and the dial which is read. While corrections following formulas are sufficient for the accuracy of which most prism instruments are capable, for the greatest precision an empirical correction curve must be constructed for the whole of each individual plate, using the comparison spectrum of standard lines which has been superposed on the spectrum being measured.

It is, of course, necessary to traverse the spectrogram or its record at least twice, once to determine the readings for standard lines, and once for both these and unknowns. In developing the first model of the present machine[1] it was thought that comparator readings would usually be slightly different when a given plate was measured a second time, even from the same starting point, because of oil viscosity variation in the screw-nut contact and other temperature effects hard to eliminate. The spectrum was therefore arranged to be recorded magnetically on a steel tape at high speed, with a scale of about 1A per meter of tape, and this tape could be sent through the reducing machine as many times as desired. After the magnetic tape method had been perfected, it was found that plate readings repeated excellently when the comparator temperature was kept constant and readings were made rapidly. The reducing machine was therefore belted direct to the comparator and the magnetic tape eliminated.

A diagram of the connected machines is shown in Fig. 3, the space between comparator and reducing machine, which is actually four feet,

[5] L. G. Hoxton, Phys. Rev. **10**, 90 (1917); J. Opt. Soc. Am. and Rev. Sci. Inst. **18**, 442 (1929); Hoxton and D. W. Mann, Bull. Am. Phys. Soc. **10**, 8 (1935). S. Grassmann, Physik. Zeits. **32**, 148 (1931). H. Conrad-Billroth, Zeits. f. Inst. **54**, 301 (1934).

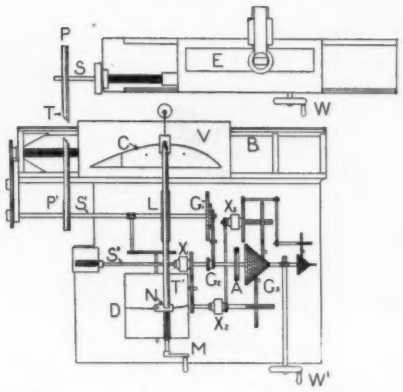

FIG. 3. Diagram of the comparator and reducing machine, showing the relationship of the principal mechanical parts.

having been omitted. An extension shaft S on ball bearings was fitted to the comparator screw, and on this was mounted a carefully turned sprocket wheel P of 8-inch diameter, provided with a single row of 128 teeth fitting standard 35 mm motion picture film perforations. A similar 4-inch wheel P' on the computing attachment shaft S' was belted to this by means of a suitable length of 5/8-in. steel tape 0.003 in. thick, provided with a single row of perforations along one edge. This was found to give a light, flexible, and rigid connection between the two machines. The comparator screw is of 2-mm pitch, and with the plate dispersion of about 0.4A/mm most frequently used,* 0.8 mm of tape corresponds to 0.001A, a scale which makes backlash and errors due to irregularities and temperature effects quite negligible.

The operator can stand or sit in front of the reducing machine and control the comparator with hand wheel W' as readily as he could directly with W; the backlash of the entire system can be made less than 0.001A, and much of this is in the comparator.

The shaft S' on which P' is mounted will be referred to as the displacement shaft, since its rotation is proportional to plate displacement l. Shaft S'' will be called the wavelength shaft, since it turns the wavelength dials directly. The problem of reduction is now to select at any instant the proper gear ratio between these two shafts, this ratio varying as the dispersion changes. An approximately correct ratio can be chosen by selecting the proper gear in set G_1 to correspond to the order of the grating used, and in set G_2 to correspond to its radius of curvature (21 ft. and 35 ft. provided). With gear set G_3 one can get any factor desired to change the ratio to correspond to the particular part of the Rowland circle on which the spectrogram under reduction was obtained. This train of gears gives great flexibility, and enables one to set any desired linear dispersion into the machine, since it consists of three sets of decimal gears with suitable differentials which can be set to add or subtract such a number of turns as will multiply the dispersion by any factor between 0.000 and 2.000 in steps of 0.001.

The proper linear dispersion for a given plate having been selected, we must next add a variable factor to correspond with the correction $\lambda_c - \lambda$ mentioned above. This is done by means of the very carefully made 1–3–4 differential L in shaft S'. By rotating the rim of L, one mm on which corresponds to 0.001A on the plate, any desired correction can be introduced, either from an auxiliary servo-mechanism designed to give a large correction (as would be required to make the machine read wave numbers directly, or for wavelengths from prism spectrograms), or as illustrated in Fig. 4.

The outer rim of differential L is provided with sprocket teeth, and a piece of steel tape T' similar to that in the belt T is passed around this so that the differential can be turned by turning handle M, or by moving carriage V. One turn of M corresponds to 0.001A on the plate, as does 0.5 mm motion of the carriage V. This carriage is moved by a template C as described below, and through this any small correction following a smooth curve can be automatically inserted if desired.

Drum D is so geared to shaft S' that it makes one complete turn while the plate is traversing the comparator, and its motion is proportional to l. A 20×8 inch sheet of paper is wrapped around D, and a stylus attached to the nut N of tape T' is arranged to mark the position of N

* In the succeeding discussion this dispersion will always be assumed when plate displacements are given in Angstroms, although the machine can be used with any dispersion.

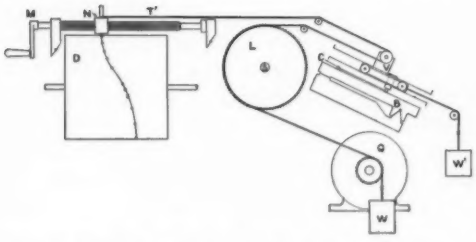

FIG. 4. Diagram of the mechanical system used to control rotation of the rim of differential L, to introduce dispersion variation.

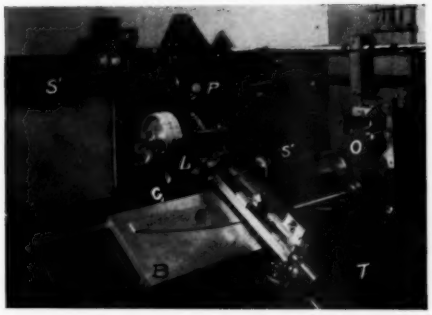

FIG. 5. View of the rear of the reducing machine, showing the template C for automatic dispersion variation, the drum L containing a rotating print of the iron spectrum, and the two nosepieces on the recording camera. The wavelengths are photographed through the downward pointing nosepiece, while the light beam from oscillograph O enters at P through a cylindrical lens.

on the drum. A curve of correction residuals can then be plotted out on D by joining with a smooth curve points obtained by making the international secondary iron standards, or other standards, have their proper wavelength readings on the machine. When this curve is followed with the stylus the machine gives the correct wavelength values for all lines.

It was found necessary to keep at least 5 lbs. tension on T (Fig. 4) to prevent small oscillations in the rim of differential L, and about 3 lbs. pressure of V against the template C. This was done by means of weights W and W', but it was found that the reversal of torque in L when the direction of rotation of the machine was reversed caused difficulty. This was remedied by introducing the torque motor Q which is arranged to give a compensating torque which reverses with the drive of the machine.

In the first model the differential L was driven directly from M with a worm drive, but it was found that the chief residual source of error was in small lateral displacements of the stylus from the correction curve on D when this had high curvature and steep slope. Accordingly the device B shown in Figs. 3, 4 and 5 was added. This consists of a carriage on 20-inch ways, driven from shaft S' at the same speed as the plate being measured. On this carriage can be fastened steel templates C cut to give the proper dispersion variation so that the correction curve on D will be a horizontal almost straight line. These templates are fairly smooth parabolas for a large concave grating, and are easy to plot and cut. Two overlapping sets of templates have been provided for the 35-ft. grating circle of the Institute, and similar sets are being provided for the 21-ft. circles. For the two-meter normal and grazing incidence vacuum spectrographs three overlapping templates suffice. Unless the highest precision is desired, the curve on drum D need not even be plotted if the comparator is thermostated to a constant temperature.

The addition of the template carriage complicates the machine somewhat (though a high class screw is not required for it), and it is not essential, but where many plates are measured in the same spectral regions this feature is a great convenience. Provision must of course be made to have a chosen line on each plate set opposite the proper mark on the template, but it is desirable to set a plate at a different position on the comparator each time it is measured to reduce any errors from the screw.

The total periodic error in the reduction system has been found to be less than 0.0003A by setting a given dispersion into G_1 and G_2 and then offsetting this with the decimal gear train G_3. The wavelength dial should then remain at rest; actually it is found to oscillate with a complex periodic motion of negligible amplitude. All gears and differentials after L can be of ordinary selected commercial grade, but L must be carefully made. Its shaft on side G_1 turns four times as fast as that on side S'.

Power to run machine and comparator comes in on shaft S'' from a d.c. shunt motor A. S'' is the shaft of highest speed, and the drive is such that in every case a high speed shaft drives one

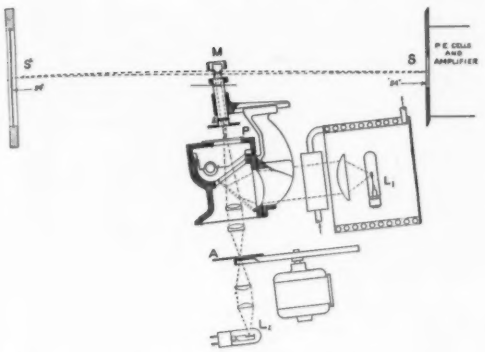

FIG. 6. Diagram of the optical system used to get a 3000-cycle beam of light for automatic recording, and an extra observing beam.

of lower speed, which gives very smooth operation.

While the machine can be readily operated through handle W', since ball bearings are used throughout, it was desired to keep the motor at A permanently belted to S''. A friction switch was mounted on the shaft of W' which energizes the motor slightly in the proper sense when the shaft is turned in either direction. For motor drive, the direction and speed of operation are controlled by a hand rheostat which can be set the desired amount either side of its neutral position.

To enable the operator to identify standard lines rapidly and plot the curve of residuals, a drum (not shown except in Figs. 1 and 5) of 8-inch diameter with a rim two inches wide is geared to shaft S'. On this is mounted a positive print of the iron comparison spectrum in the proper region, with all important wavelengths marked. This print moves in synchronism with the plate directly in front of the operator and enables him to identify iron lines at a glance. In preparing the correction curve he sets a standard wavelength value into the wavelength dials, and sees on screen S' before him (Figs. 5 and 6) a spectrum line, perhaps slightly off the fiducial mark. He turns handle M until the line is accurately centered and presses the stylus on N to make a mark on D. This is done for 20 or 30 lines and a smooth curve is drawn between the points. By following this curve with the stylus, wavelength values which reproduce to 0.001A can be obtained directly at any speed.

§4. Automatic Setting on Spectrum Lines

A very important improvement in comparators ascribed to Siegbahn is that in which an image of the plate being measured is projected on a screen in front of the operator, thus eliminating the necessity of observing the spectrum through a microscope. An incidental advantage of this is that each operator can draw on the screen with a pen the type of fiducial mark which he prefers. In this laboratory a short straight line which stops in the middle of the spectrum line and is parallel to it is used; such a "half cross hair" would be difficult to realize conveniently in a microscope.

The chief drawback to the projection method comes from the heat put into the comparator by the light beam traversing it. Using a 500-watt projection lamp we found a 90-minute warming period necessary before equilibrium was reached, even when a two-inch water cell was used to filter infrared from the beam. The efficiency of the optical system was improved until a 100-watt lamp was found sufficient for eye observation, while for automatic setting a 3-volt straight filament lamp carrying 2.75 amp. suffices.

The optical system used is shown in Fig. 6. For visual observation light from the 100-watt lamp L_1 is focused on projection lens l_1 through the plate P being measured. Lens l_1 throws a 30-fold (or 15-fold if desired) enlarged image of portions of P on screens S and S', light from the upper half of a spectrum line being sent to one and from the lower to the other by means of the double mirror M. The operator observes the spectrum on S', which is of ground glass, while light striking S passes through a slit as in a projection microphotometer and operates an a.c. amplifier system through photo-cells.

Light from L_2 passes through a disk driven by an 1800 r.p.m. synchronous motor which chops the beam to give 3000 flashes per second. An image of slit A is thrown on the plate P, and the intermittent light traversing this also reaches screens S and S'. The operator can use either beam for observation, but only the chopped beam operates the amplifying system.

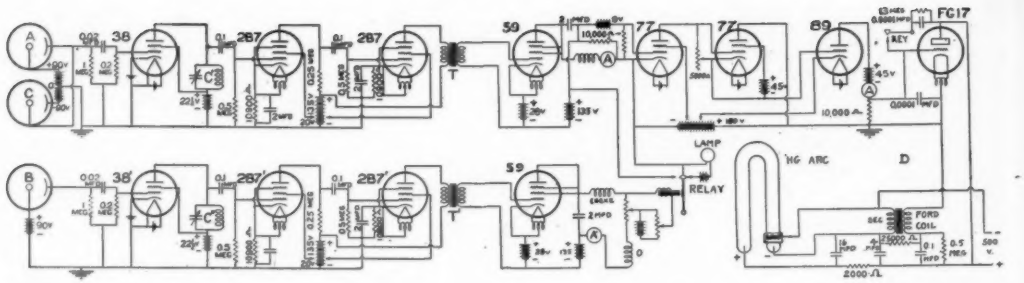

FIG. 7. The electrical circuits used to flash the mercury arc whenever the light intensities on cells *A* and *C* are equal, if the light on cell *B* has fallen below a predetermined value. Both amplifiers are tuned broadly to 3000 cycles, giving fairly uniform response between 2600 and 3400 cycles to allow of modulation between 0 and 400 cycles in crossing spectrum lines at high speed.

The light which strikes the slit (100×5 to 0 mm) in screen *S* is divided laterally into three parts by means of glass rhombs. That part of the beam which traverses the left rhomb is focused roughly on photo-cell *A* (Fig. 7), that which traverses the center half of the slit falls on cell *B*, and that which goes through the right-hand rhomb falls on cell *C*, these being identical General Electric FG 114 vacuum cells, carefully shielded.

In Fig. 7 is shown the combination of circuits used to give automatic line setting and an intensity (density) curve. Cells *A* and *C* are connected in opposition, and their difference current is amplified in a circuit broadly tuned to 3000 cycles by means of tuned impedance coupling at *C* and by means of the peaked transformer *T*. After 800,000-fold voltage amplification the output current is rectified in tube 59 and the d.c. component emerges as a variation in potential across a resistance of 10,000 ohms which in the case of sharp and narrow lines is over 100 volts. The variation of voltage in such a case is shown in curve *A–C* of Fig. 8. Since we are only interested in the points like *F* on this curve where the voltage falls to a certain constant minimum, this is fed through a Horton d.c. amplifier[6] and amplified 400 times more. This amplifier is saturated whenever the voltage across its input exceeds 0.25 volt, but whenever it falls below this amount the output voltage falls from its 90-volt saturation value, which has been keeping the grid of the thyratron FG-17 negative, and makes this more positive. A typical output curve of the Horton amplifier is shown in curve *H* of Fig. 8. As soon as the thyratron grid rises above 7 volts negative its circuit is tripped and the 20 mfd condenser is discharged through the mercury arc.

The entire problem in making this circuit function satisfactorily is one of shielding and otherwise inducing steadiness. As it is at present constituted fluctuations of about 20 volts exist in the potential on the thyratron grid (curve *H*) but even so reproducible results are obtained on most spectrum lines to well within 0.001A. Even with hand setting, apparatus giving curves like *A–C* or *H* is very useful, since a definite reading which is the same for all lines marks the line peak.

Returning to the center beam of light traversing the slit *N*, current from cell *B* is sent through another a.c. amplifier similar to that described, and the rectified output is fed through a simple moving magnet oscillograph *O* and a milliammeter.

The deflections of these give the density curve of the spectrogram, and light from the mirror of the oscillograph traces this curve on the same film which records the wavelengths in the camera (see Fig. 2b).

The thyratron having been arranged to flash the mercury arc whenever the slope of the curve *B* (Fig. 8) differs from zero by less than a predetermined amount, it is necessary to differ-

[6] J. W. Horton, J. Frank. Inst. **216**, 749 (1933). I am greatly indebted to Dr. Horton for calling the possibilities of his amplifier to my attention in this connection, and for much valuable advice regarding the electrical circuits used in the line-setting device.

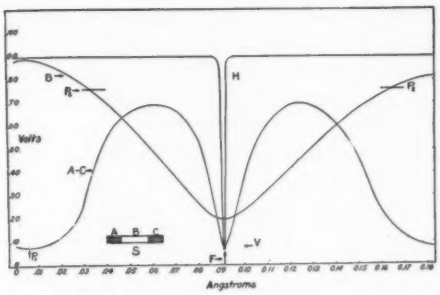

FIG. 8. Typical curves obtained in crossing a spectrum line: B, the amplified current from cell B, giving the density trace and operating the line-selector relay; $A-C$, the amplified difference current from cells A and C, giving the density slope at any instant; H, the voltage from a d.c. amplifier into which voltage following curve $A-C$ has been sent, the amplifier being saturated except when $A-C$ falls to within 0.25 volt of its minimum value. The width of the slit in screen S used in obtaining the curves is as shown. It was set for a resolution of about 200,000; the shaded regions are those whose light is thrown by glass rhombs on cells A and C, respectively, while light entering region B is used to make the density trace.

entiate between zero slope occurring between lines (as at point P_1) and the desired points of type F. This has been done by connecting the output of the intensity amplifier (at Q in Fig. 7) to keep the thyratron grid negative unless a line is being traversed. The circuit can be adjusted by means of a potentiometer to operate the relay whenever the current falls below some desired value, so that only lines more intense than some chosen amount will be recorded. As soon as a point such as P_2 is reached on a line, the intensity amplifier loses control of the thyratron and the slope amplifier takes it, keeping the thyratron grid negative until the point F is reached when it is allowed to flash the mercury arc, recording the wavelength. The intensity curve is usually recorded continuously, as in Fig. 2b, though it can also be arranged to record an intensity dot on the wavelength record when uniform wavelength spacing is desired (Fig. 2a).

§5. CONCLUSION

While the reducing and recording features have been in use for a sufficient time to allow the elimination of points of weakness and to test their value, the automatic line setting device is admittedly still in the experimental stage. Nevertheless the present model has so exceeded expectations in the speed and accuracy of its results that there can be no question as to the value of developing it further. When a number of obvious improvements have been made it should be no more difficult to set up and use than an ordinary microphotometer.

To test the action of the automatic setting device, a line of moderate intensity and sharpness was run across 50 times. In the recorded list of wavelength values, the maximum deviation from the mean was ± 0.0006A, and the average deviation ± 0.0003A. With hand setting on the same line, the corresponding deviations were ± 0.004A and ± 0.001A. A group of twenty lines was run across ten times with automatic setting, and the density curves and wavelength values recorded were identical to well within the required tolerance, while the values agreed with those obtained by hand setting, but were more self-consistent.

Since the device records a wavelength value whenever a point of zero density slope is reached at finite density, minima as well as maxima are recorded for self-reversed and close lines. This is desirable for the former, and does no harm for the latter except to make the record somewhat difficult to decipher when the lines are very close together. A more disagreeable feature is the tendency to record a whole series of values as the wing of a very broad line moves across the measuring beam; here the slope is often so gradual that slight irregularities produce maxima and minima. Having a density trace, as in Fig. 2b, makes interpretation of such aberrations easy, however.

With all automatic features running as at present, final wavelength values can be obtained for 100 lines per minute without difficulty, and as soon as a vacuum tube system is substituted for the relay of Fig. 7 there should be no difficulty in increasing this figure by a factor of five. These figures correspond to a gain in speed of the present apparatus over nonautomatic methods of from 200 to 1000-fold, with at least a twofold increase in average precision, but such a speed comparison is hardly fair because of the time required to set up the correction curve for a plate in the machine, which is about half an hour. A conservative figure for the overall gain is from 10 to 200-fold, depending of course upon the type of spectrogram measured, and the gain

is particularly favorable in the case of complicated spectra.

The tripartite slit in screen S must be adjusted periodically to insure balance of the beams entering cells A and C when no plate is on the comparator. To make this balancing operation easier (the cells are balanced to 0.1 percent), narrow shutters are provided which can be pushed into place by means of screw adjustments so that more or less of the length of each slit portion can be covered from each end. If the balance is inexact the wavelengths recorded will not be those corresponding to density maxima, but will lie to one side of this point. The presence of this type of offset can be determined by crossing the line in both directions; if the two values do not agree when mechanical backlash has been taken care of, the balance is incorrect.

It would, of course, be more satisfactory to use a single photo-cell instead of A and C, and there are a number of ways in which this could be done. Sears[7] has recently devised a contrast densitometer which could be used for a maximum setter, in which the plate is oscillated laterally, producing an alternating light fluctuation whenever the density slope is not zero. Hardy[8] in his color analyzer uses a rotating Rochon prism to produce two beams of polarized light which could be used in the same way. Neither of these devices is at present suited to give the high frequency alternations desired for the present machine, but developments are now under way to substitute something of the sort for the present complicated optical and amplifier system. Using a high frequency field on a Kerr or Faraday cell to produce two pulsating polarized beams falling on a single photo-cell, with a secondary modulation of the light source, would appear to give a means of using a single photo-cell and amplifier to record both density and density-slope.

The development of the device described in this paper has been aided by advice and encouragement from, and by useful suggestions on the part of so many of my colleagues that individual acknowledgments to all are impossible; special thanks are due, however, in addition to those already recorded, to Professor W. B. Nottingham and Mr. Walter Kallenbach for valuable advice and assistance with the electrical and mechanical systems, respectively. I am especially indebted to Dean Vannevar Bush for many valuable suggestions, for so kindly placing his great experience with calculating machinery at my disposal, and for his early conviction that the device was practicable. The smooth functioning of the machine is due to the skill of Mr. Carl Selig, expert instrument maker, who constructed it.

[7] F. W. Sears, J. Opt. Soc. Am. **25**, 162 (1935).
[8] A. C. Hardy, J. Opt. Soc. Am. **24**, 162 (1934).

On the Nature of Unpolarized Light

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All that can be affirmed regarding the nature of unpolarized light is that it shows no preferential polarization. When, for instance, unpolarized light enters a quartz crystal in a direction parallel to the axis, the light is decomposed into right- and left-circularly polarized beams of equal intensity. This was demonstrated experimentally by Fresnel. By the use of right- and left-handed quartz crystals in the two paths of an interferometer, interference effects occur whose nature can be definitely predicted on the assumption of the existence of such circularly polarized components. An experiment of this nature has been performed by Langsdorf and DuBridge, but the experiment, in itself, furnishes no information as to the nature of unpolarized light.

LANGSDORF and DuBridge[1] have described an interesting experiment in a paper entitled *Optical Rotation of Unpolarized Light.* In a note at the end of their paper R. W. Wood mentions an earlier experiment by Stefan[2] which is similar in principle to that of L. and D. These experiments are also described by Wood in his well-known text.[3]

In L. and D.'s experiment, which alone is discussed here, unpolarized monochromatic light was broken into two beams of equal intensity by an interferometer (in their apparatus, by a Fresnel biprism) so that a set of interference fringes was formed in the region where the two beams were reunited. Into the path of each of the two beams there was then inserted an optically active substance, such as quartz,[4] with its axis parallel to the direction of propagation of the light. One quartz was right-handed and the other left-handed, and each was of such thickness as to rotate the plane of polarization of incident plane-polarized light through 45°. By using unpolarized light under these conditions the fringes completely disappeared.

L. and D. remark "whether any effect would be expected depends on the view we adopt as to the nature of an unpolarized light beam. Let us regard it as made up of a large number of elementary components (photons?), each emanating from an individual atom or molecule in the source and each being plane-polarized, the polarization planes for the various components having a random distribution about the axis of the main beam." With this assumption L. and D. show that the interference fringes should disappear. Wood[3] writes "A. Langsdorf and L. DuBridge have described an interesting experiment which may be regarded as showing the presence of the variously oriented polarized components of ordinary unpolarized light." It appears to me, however, that this experiment gives no information whatsoever on the nature of unpolarized light. The fringes should disappear, regardless of the assumptions made. The experiment merely confirms the well-known action of quartz on light traveling parallel to the optic axis. L. and D. also state "nor have we found any statement in the standard treatises on optics which would enable us to predict with certainty what the result of the experiment would be." Because of this last statement, with which the writer concurs, it seems desirable to publish the following rather detailed discussion.

Fresnel assumed that any sort of light, polarized or unpolarized, when incident normally on a quartz surface cut perpendicular to the optic axis, is broken into two beams, one of right-circular polarization, and the other of left-circular, which travel with different velocities. Fresnel made a direct experimental test of these assumptions. He used a train of alternate right- and left-handed quartz prisms to separate in angle the two beams, and then tested the polarization of each. The only positive statement that we can make regarding the nature of unpolarized light is that it exhibits no preferential polarization, and this, as a matter of fact, is

[1] A. Langsdorf and L. A. DuBridge, J. Opt. Soc. Am. **24**, 1 (1934). To be referred to as "L. and D."

[2] Stefan, Sitz. Ber. Wien. Akad. **50**, 380 (1864).

[3] R. W. Wood, *Physical Optics* 3rd ed., Macmillan Co., 1934, pp. 362, 829.

[4] Sugar solutions were actually used by L. and D., because of lack of suitable quartz plates.

merely a working definition of the term "unpolarized light." If such light is tested with a Nicol, the intensity of the transmitted plane-polarized light is found to be independent of the orientation of the Nicol. If it is decomposed in any way into right- and left-circularly polarized beams, the intensity of the two beams is the same. Hence in the experiment under discussion we can feel confident that each light beam, on entering the inserted quartz crystal, breaks up into two beams of *equal* intensity, one right-circularly polarized and the other left-circularly polarized. What effects should now be produced, when all of the beams are reunited?

Let us consider first the situation before the quartz plates are inserted. For some point on the screen the optical path lengths for the two interfering beams will be equal. We take this as our fiducial point O. At this point there occurs the center of a bright fringe. If we now insert into each beam, in place of quartz, an ordinary uniaxial crystal (i.e., one not optically active) with its axis parallel to the direction of propagation, our fiducial point O will be displaced to the right or left, unless the two pieces of crystal are of precisely the same thickness. Such a shift is immaterial to the argument and we therefore assume, for simplicity, that the thicknesses *are* identical and that there is no resulting shift of O. We now replace the two crystals by right- and left-handed quartz, respectively, of such thickness that in one the right-circular beam gets one-quarter of a wavelength ahead of the left-circular beam, and in the other one-quarter of a wavelength behind. The proper thickness to use is determined experimentally by the fact that it is sufficient to rotate incident plane-polarized light through a 45° angle.

We now have four beams of light, two right-circularly polarized, and two left-circularly polarized, and all four of equal intensity. The two right-circular beams are coherent and are capable of interference, when reunited. However, the *optical* path for one in the quartz is longer than that for the other. In fact the speed of the *right*-circularly polarized light in *left*-handed quartz is just that of *left*-circularly polarized light in *right*-handed quartz. Since we have chosen the thickness of the right-handed quartz such that the right-circular beam gains $\lambda/4$ over the left-circular, this means that it also gains $\lambda/4$ over the *right*-circular beam that has passed through the *left*-handed quartz. Hence at our fiducial point O the two right-circular beams arrive 90° out of phase, and the *resulting fringe system formed by right-circularly polarized light* has its fiducial point O' shifted to one side—let us say to the right—by one-quarter the distance between fringes. The two left-circular beams similarly arrive at O 90° out of phase, but the velocities are interchanged, so that the fiducial (zero path difference) point O'' of the fringe system consisting of *left*-circularly polarized light is shifted to the *left* by one-quarter of the fringe separations. Our two sets of fringes, one due to the interference of right-circular beams, and the other of left-circular beams, are thus displaced relative to one another by just half the fringe separation. The two fringe systems are necessarily of equal intensity, since they are formed of the equal amounts of right- and left-circularly polarized light into which the original unpolarized beam was decomposed by the quartz. The final resultant intensity is therefore uniform.

Although the *intensity* is uniform at all points on the screen, the state of polarization is not. At one set of points, centered on O', the light is wholly right-circularly polarized, since at these points the intensity of the left-circular light is zero. At another set of points, centered on O'' and lying just intermediate between the first set, the light is wholly left-circularly polarized. At all other points there is a mixture of right- and left-circularly polarized light. By using a quarter-wave plate and properly oriented analyzing Nicol, one can cut out completely the right-circularly polarized set of fringes, leaving only the left-polarized set. By then turning the Nicol through 90°, the right-polarized set of fringes is alone transmitted, the illumination on the screen in the two cases being just complementary. This experiment was performed by L. and D., with exactly these expected results.

It is evident, from the foregoing discussion, that the displacement of one set of fringes, relative to the other, is directly proportional to the path difference between the right- and left-circular beams produced by the quartz. Hence it is only for $\lambda/4$ path difference (or $n\lambda/2+\lambda/4$ in general) that the resulting intensity is uniform.

If the path difference is $n\lambda/2$ (n=integer), there will be no resultant blurring of the fringes, when the quartz plates are inserted. Now the optical path difference of right- and left-circularly polarized light in quartz of a given thickness varies with the frequency of the light used. Hence the fringes may completely disappear for one frequency, and be quite distinct for another. This was shown by Stefan,[2] in the original experiment on this matter.

For the purpose of this paper the important characteristic of the foregoing argument is that it includes no assumption regarding the nature of unpolarized light save that such light is decomposed by quartz into equal amounts of right- and left-circularly polarized light, traveling with different velocities. But in view of Fresnel's work this is more nearly an experimental fact than an assumption. Hence the L. and D. experiment gives no further information on the nature of unpolarized light.

It is important to notice also that only classical physics is needed in order to predict the experimental results. In the classical physics two elementary coherent light beams, i.e., two beams capable of interference, are thought of as produced originally by a single real source, without any specification as to whether this source is an atom, a molecule, or an aggregate of molecules. The maximum path difference over which interference is observed to occur may be interpreted as the length of such an elementary wave train. In the case of quantum phenomena, as is well known, we are forced to postulate the existence of corpuscular radiant energy ($h\nu$) and momentum ($h\nu/c$), to which the term "photon" is applied. This term is sometimes applied also to any elementary coherent light train of classical physics. One way in which classical interference phenomena, and the superposition principle on which they are based, can be incorporated into the newer quantum mechanics has been indicated by Dirac.[5] Such a discussion, although very illuminating, is quite irrelevant to the subject matter in question here.

If we wish, on the basis of classical physics, to make any assumption as to the nature of the polarization of *each* elementary wave train, our best experimental evidence comes from the Zeeman effect. This effect shows us that if all the atoms in an assembly are oriented with respect to some preferred direction (the direction of the magnetic field) the emitted light is *elliptically* polarized. The ellipses are of all possible shapes, depending on the direction in which the light is viewed, and in certain special directions the ellipse takes on the special form of a straight line or of a circle. But the amount of such linear or circularly polarized light is infinitesimal, compared to the amount of elliptically polarized light, when all directions of emission are considered. Now the integrated light emitted in *all* directions by an assembly of atoms oriented with respect to some *one* preferred direction, should be similar in character to the light emitted in *one* direction by an assembly of atoms oriented (at random) in *all* directions. Hence it seems natural to consider unpolarized light as a mixture of *elliptically* polarized components, the ellipses being of every possible shape. I can see no scientific reason for the assumption, so commonly made in texts, that unpolarized light consists of *plane*-polarized components, oriented in all azimuths.

This is, however, merely a matter of mathematics. An elliptic vibration can be considered as the superposition of two linear vibrations, at right angles, and of different amplitudes and phases. But it can equally well be considered as the superposition of two circular motions, one right-circular and the other left-circular, of different amplitudes and phases. If elliptic polarized light enters a quartz crystal so as to travel inside the crystal at right angles to the optic axis, we know that it breaks up into two plane-polarized components, traveling with different velocities. If this same light enters the crystal parallel to the optic axis, it breaks up into right- and left-circularly polarized components, traveling with different velocities. It is thus evident that any particular set of components cannot be said to be present in the original light. On the contrary, such a set is *manufactured* by the quartz,[6] just as the series of monochromatic

[5] P. A. M. Dirac, *Principles of Quantum Mechanics*, 1930, Chapter I.

[6] The action of quartz on unpolarized incident light is a good illustration of the arbitrary character of the manufactured components. In general the light splits into two

beams reflected from a grating, when white light is incident upon it, is *manufactured* by the grating. If we are given any number of coherent beams of light, of specified polarizations, intensities, and phase relations, we can by means of the principle of superposition calculate uniquely the character of the resulting light produced by interference. But given *only* the nature of the resultant light, we can deduce nothing as to the specific character of its components, for there are an infinite number of different sets of components that may be superposed to produce exactly the same resultant light beam. This is just the situation in the L. and D. experiment. From a knowledge of the presence of right- and left-circularly polarized beams inside the quartz, we can deduce nothing as to the polarization of the individual light trains that produced them.

Let us return, however, to our assumption that each individual wave train consists of elliptically polarized light. This is split into two parts by the interferometer, and then each part is again split into two parts by the quartz. The right- and left-circular components will be of equal intensity only in the special case where the original wave train was plane-polarized. We now assume that *each* elementary wave train may produce its own set of interference fringes, and when it is broken into right- and left-circular components, as in the L. and D. experiment, each such train produces not one, but two such sets of fringes, one of right- and the other of left-circularly polarized light. The two sets of fringes are exactly out of step. They are, however, not in general of equal intensity, so far as one original wave train is concerned. But the position on the screen is the same for all sets of right-circular polarized fringes,—similarly for left-circular polarized. If the original light is unpolarized there must be, in the aggregate, equal amounts of the two sorts of polarization. Hence the sum of the intensities of all the sets of right-circularly polarized fringes must equal the sum of all left-polarized fringes, and the final resultant intensity is uniform.

It seems safe to conclude that no experiment can give us any information on the nature of unpolarized light, further than that which we now have; namely, that *if* such light is split into components, in any given apparatus, no preferential polarization will be found. If the splitting is into plane-polarized components, all azimuths will be equally intense. If it is split into circularly polarized components, the right- and left-circular members will be equally intense, etc. I am confident that many persons, in the past, must have themselves gone through the foregoing train of reasoning. As already noted, however, such a discussion does not appear in any of the best known texts on physical optics (in particular, texts written in English), and it has therefore seemed desirable to publish these details.

elliptic vibrations, one right-handed and the other left-handed. The shape and size of the two ellipses are the same, but the major axes are at right angles. For the special direction parallel to the optic axis the two ellipses become circles. For the special set of directions at right angles to the axis the ellipses degenerate into two linear vibrations, at right angles to each other. In all cases the two components are of equal intensity. With incident *polarized* light of any character whatsoever the only difference in the result is that the two components produced by the quartz are in general of *unequal* intensity.

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Comments on the Paper by R. T. Birge "On the Nature of Unpolarized Light"

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PROFESSOR BIRGE has greatly clarified, by his discussion in the above paper, certain questions raised in our paper on *The Optical Rotation of Unpolarized Light.* I am quite in agreement with his conclusion that any particular method of resolving unpolarized light into components is quite arbitrary. As far as the light beam in the optically active substance is concerned, it is immaterial whether we deal with linearly, elliptically or circularly polarized components since they all lead to the same result. Our suggestion of a resolution into plane-polar-

ized components was a simple and obvious one, although, as Professor Birge has shown, it is not unique.

However, the chief purpose of our experiment (as indicated by the title of the paper) was to determine whether optically active substances produced *any observable* effect on unpolarized light, and such an effect was indeed found. So far as we were able to learn at the time, this question had not been answered by previous experiments of this kind. Professor Wood called attention to the paper by Stefan, and quite recently my attention has been called to a paper published in 1932 by S. Wawilow entitled *On Some Cases of Interference of Natural Bundles* (in Russian).[1] In this paper several experiments bearing on this subject are described, one of which is quite similar to ours, except that a Rayleigh interferometer was used in place of the Fresnel biprism. These experiments show that by means of optically active materials it is possible to produce two beams of "natural" (unpolarized) light which originated in the same source but which do not produce an interference pattern of the usual type. Wawilow and Brumberg[2] have described another experiment which shows that a similar result may be obtained without the use of optically active materials. This experiment consists essentially of selecting two beams which emerge in antiparallel directions from a small source and then reflecting each through 90° by mirrors to bring them into parallelism. In this case also it is found that the interference field is uniformly illuminated, a fact which is readily understood if the beams are resolved into plane or circularly polarized components.

Now normally when we find two beams of unpolarized light which combine to produce uniform illumination we say that the beams are "noncoherent." In our experiment, however, a closer examination of the field with a quarter wave plate and Nicol prism shows that there are really two overlapping sets of fringes, one produced by left- and the other by right-circularly polarized light. In other words the corresponding components of the beam are still coherent. It is this peculiar type of coherence to which we wished to call attention. It is not a new phenomenon and is, of course, readily understood in terms of present knowledge concerning the behavior of light, but it seems to be of sufficient interest to merit more attention than it has been given in usual discussions of the subject. The type of coherence possessed by two unpolarized beams is not revealed by ordinary polarization experiments.

In describing and understanding interference experiments of this kind it is most convenient—possibly necessary for most of us—to resolve (mentally) the interfering beams into some combination of polarized components. We find indeed that these components produce separate sets of interference fringes and may, as in Fresnel's experiments, actually become separated in angle. We do not of course think of these components as having an independent existence in the original beam any more than we think of the arbitrary components into which we might resolve a vector as having "existence" in the vector itself.

In conclusion I may say that the purpose of our paper was to call attention to these phenomena and not to interpret them as giving any new information about the nature of unpolarized light. We hoped that its publication would result in a further discussion of the subject and Professor Birge's paper now justifies this hope.[3]

[1] S. I. Wawilow, Bull. Acad. Sci. U. S. S. R., p. 1451 (1932). (I am indebted to Professor J. K. Kostko of Washington University for his translation of this paper.)

[2] S. I. Wawilow and E. M. Brumberg, Physik. Zeits. d. Sowjetunion **3**, 103 (1933).

[3] I have discussed these matters in some detail by correspondence with Professor Birge and we are now in substantial agreement as to the interpretation of these experiments.

Cadmium Magnesium Alloy Photo-Tubes

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(Received March 26, 1935)

IN comparing various sources of ultraviolet radiation in order to evaluate their effectiveness in producing erythema, a photoelectric tube, with a response limited to a narrow region of the spectrum, is required. Cadmium photo-tubes in quartz bulbs have been used for this purpose in the past.[1–4] While the spectral response of cadmium is in fair agreement with the erythema curve on the long wave side, it is too high for the shorter wavelengths, as can be seen from Fig. 4 of Taylor's paper. This effect has been partially corrected by the use either of filters or of corex glass for photo-tube bulbs. The low transmission of the corex for the shorter ultraviolet radiation brings the response into closer agreement with the erythema curve. Tubes of this kind have been made by Dr. Roberts of the Nela Park Lamp Development Laboratory, and their use in appraising erythemal ultraviolet radiation has been described by Taylor.[5]

In order to obtain a still better agreement between the erythema curve and the tube response, cathodes of cadmium magnesium alloy of various composition were investigated. Cadmium and magnesium are mixible in all proportions, and the resulting alloy is a soft, bright, nontarnishing metal.

Two spectral sensitivity curves are shown in Fig. 1. They have been adjusted to the same peak value. The heavy curve is for a cathode of 95 percent Cd, 5 percent Mg, and the dotted curve for a cathode of 5 percent Cd, and 95 percent Mg. The curves show that increasing the concentration of Mg increases the relative response to long wave radiation, while increasing the concentration of cadmium increases the relative response to short wave radiation. The maximum in the curves is not a true characteristic of the cathodes but is determined by the falling transmission of the corex toward the shorter wavelengths.

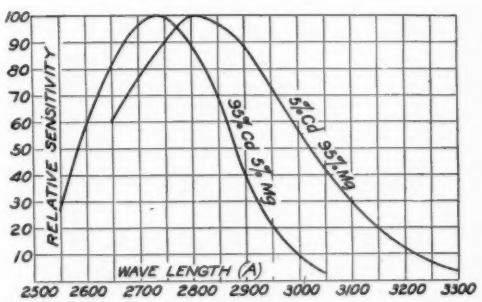

FIG. 1. Relative spectral sensitivity of cadmium alloy photo-tubes.

Cathodes have been studied with alloys intermediate in composition between these two. With the present technique, however, the difference between alloys differing in composition by 10 percent is less than the difference between individual tubes.

[1] Dorno, *Zur Technik der Strahlungsmessungen*, Strahlentherapie **18**, 177 (1924).

[2] Pohle and Sawyer, *The Calibration of the Mercury Vapor Lamp in Reproducible Units for Clinical Purposes*, Am. J. Roent. and Rad. Ther. **20**, 338 (1928).

[3] Ruttenauer, *Über Erfahrungen bei U.V.-Messungen mit der Cadmiumzelle*, Strahlentherapie **31**, 349 (1929).

[4] Schwarzchild, *Ultraviolet Measurement with the Cadmium Photoelectric Cell*, Am. J. Roent. and Rad. Ther. **26**, 272 (1931).

[5] A. H. Taylor, *The Measurement of Erythemal Ultraviolet Radiation*, J. Opt. Soc. Am. **23**, 60 (1933).

An Optical Device to Aid in Mapping from Photographs

O. M. MILLER, *American Geographical Society*

(Received April 4, 1935)

THE operation of the single eyepiece oblique plotter which is being used at the American Geographical Society[1] enables level features, such as coastlines, to be drawn directly in plan from their perspective images appearing on high oblique photographs, that is to say, those taken with the camera axis pointing more nearly horizontal than vertical. Where the ground is not flat, the instrument can be operated to obtain the positions of points both in plan and in elevation by plotting the intersection of corresponding perspective rays from two photographs.

Fig. 1 is a perspective diagram which shows the geometrical relationship between the horizontal plane, the tilted photograph in its positive form and the perspective center S, at the moment of exposure. S corresponds to the back nodal point of the camera lens as far as the photograph is concerned, the front nodal point as far as the ground or map is concerned and the virtual position of the observer's eye as far as a plotting mechanism is concerned. When the photograph is placed in its correct relative orientation to the map or ground plane then a line between any point on the ground and its image on the photograph if produced must pass through S. If the ground is flat then this line can also be considered to pass through the map position of the point (see Fig. 2). If the ground is not flat then the perspective ray between any point above the ground datum level and S will not pass through the map position of the point (see Fig. 3).

However, the perspective center, the photographic image of the point and the map position of the point all lie in the same vertical plane so that though the actual map position of the point cannot be determined from one photograph its direction from the camera position can be obtained.

As far as flat country is concerned, Fig. 2 immediately suggests a simple though crude plotting apparatus. By using a positive transparency and by placing the observer's eye behind a small aperture at S the image of the point of a plotting pencil moving in the map plane will be seen superimposed on the photograph. By moving the pencil under the features on the photograph their plan outline can be plotted roughly. If the aperture is made small enough virtually to eliminate parallax errors and focusing difficulties, problems of illumination immediately arise.

E. Deville,[2] the late Surveyor-General of Canada, in proposing a form of stereoscopic plotter, suggested placing half-silvered mirrors in front of two apertures, one for each eye. In this proposal an index mark attached to a plotting pencil was observed directly and the photographs were observed by reflection. The use of half-silvered mirrors, however, merely extended the use of the device to stereoscopic measurement but did not solve the problems of focus and illumination.[3]

One solution of these problems is the use of what may be called a pinhole mirror, and this device has been incorporated into the oblique plotter whose main features will now be described briefly.

Fig. 4 is a photograph and Fig. 5 is a diagrammatic outline of the oblique plotter as at present constructed. A horizontal axis t–t is mounted on the vertical standard (1) so that it can be moved up and down the latter, by turning the

[1] The instrument has been built by the Mann Instrument Company and the author is indebted to Mr. David W. Mann and his assistant, Mr. K. W. Harper, for their working out of the constructional details. He is also indebted to Mr. George A. Thorne, Jr. for his active support of the project, and to the American Geographical Society for the facilities which it has placed at his disposal.

[2] E. Deville, *On the Use of the Wheatstone Stereoscope in Photographic Surveying*, Trans. Roy. Soc. Canada **8**, 63 (1902).

[3] For brief descriptions of other developments in plotting instruments in which real index marks are used, see O. von Gruber, *Photogrammetry: Collected Lectures and Essays*, translated from the German original by G. T. McCaw and F. A. Cazalet, American Photographic Publishing Co., Boston, 1932, pp. 176–181, 221–223.

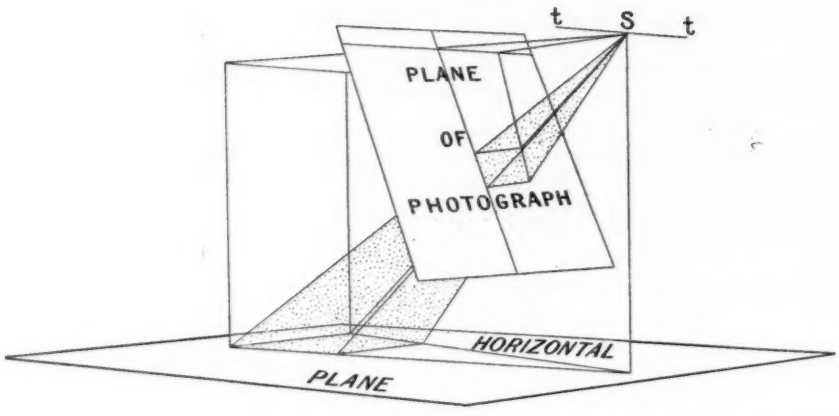

FIG. 1. Perspective diagram showing relationships between the perspective center S, a tilted photograph and a horizontal plane.

crank (2), the height of the axis being read on a drum (3). t–t is the tilt axis about which the pinhole mirror S, a photograph holder (4) in which a negative is placed, and a viewing apparatus (5) can be rotated together by turning the crank (6), the tilt being read on the drum (7). The mirror consists of a fully reflecting plane surface in the center of which is a pinhole aperture about one-third of a millimeter in diameter. The mirror is adjusted so that the tilt axis lies in its plane and the pinhole is centered on the tilt axis. The photograph holder is adjusted so that the plate perpendicular corresponding to the optical axis of the camera cuts the tilt axis normally at the pinhole. Slow motion movements are provided for swinging the photograph in its own plane about the plate perpendicular and for setting the photograph at its equivalent focal distance from the pinhole, and vernier scales are provided for reading the amounts of these movements.

The inclination of the plate perpendicular to the plane of the mirror is actually about 60° though theoretically the instrument would function at other inclinations also. The important thing to know, however, is the inclination of the reflected ray to the horizontal map plane as this corresponds to the angle of depression or elevation.

The viewing apparatus (5) consists of a periscope whose optical axis lies in the tilt plane and always points to the pinhole. This part of the instrument will be described more fully later.

Attached to and vertically above a plotting pencil (8) which, when operating, touches the surface of the plotting table (9), is an index mark (10) consisting of a small aperture illuminated from behind through a condenser lens. The index mark and pencil are attached to a carriage which is free to move along the horizontal bar (11). The bar (11) is free to swing around the vertical axis passing through the pinhole. By turning the crank (12) the bar is made to swing and a drum is attached which reads changes in horizontal direction. By turning the crank (13), the pencil and index mark carriage is made to move along the bar and a drum is attached which reads distances out from the center of rotation. The pencil can be lifted off the plotting

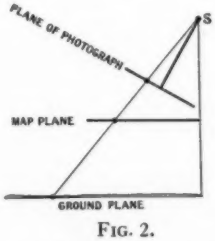

FIG. 2.

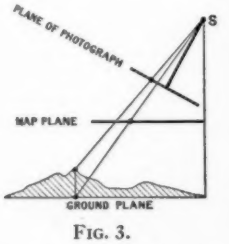

FIG. 3.

FIGS. 2 AND 3. Illustrating the effects of the heights of objects in the positions of their images in a tilted photograph. The paper represents a vertical plane passing through the perspective center S.

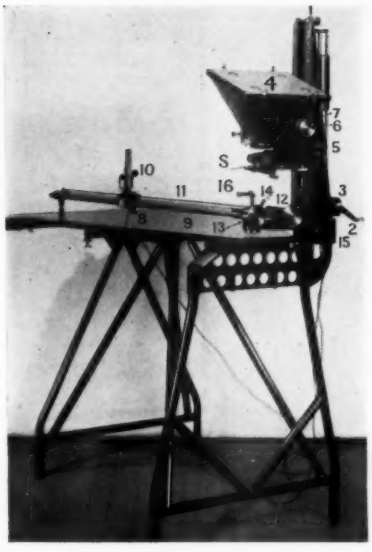

FIG. 4.

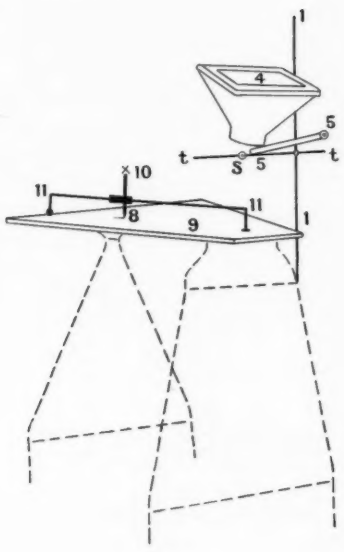

FIG. 5.

FIGS. 4 AND 5. A photograph and simplified perspective drawing of the single eyepiece oblique plotter being used at the American Geographical Society.

table by means of a bar lever operated at (14). The intensity of the illumination of the index mark is controlled by a rheostat situated at (15) and it has been found convenient to make the color of the illumination green or red. The angular scales on the instrument read to the nearest minute and the linear scales all read to the nearest 0.1 of a mm.

It will be apparent from the above description that the pinhole corresponds to the perspective center S of Fig. 1 and that very thin pencils of rays from the index mark on passing through the pinhole are enveloped by corresponding pencils of rays from point images in the photograph. The effect to the observer looking through the periscope is to see the image of the index mark superimposed on the photograph. The periscope functions solely as a viewing apparatus whereby the eye is placed virtually at the pinhole. Theoretically, the pencils of rays from the point images in the photograph should be made parallel before being reflected from the pinhole mirror by means of an auxiliary lens placed between the photograph and the pinhole, but it has been found when this is not used that by limiting the size of the mirror surface and by using a low power viewing apparatus, good definition and sufficient illumination of the photograph can be maintained without introducing apparent parallax. The plateholder, however, is easily detachable from the rest of the instrument and an auxiliary lens could be placed in position without difficulty.

With the periscope focused on the photograph the index mark can be seen in sharp definition over a wide range, actually on the instrument built from less than 10 cm to a meter out from the pinhole.

A further advantage of using an illuminated index mark and a pinhole mirror is that other objects behind the mirror not illuminated as brightly as the index mark cannot be seen with the result that the image of the photograph is not confused.

As regards operating performance the preliminary tests of the instrument indicate that it is capable of plotting and recording directions correctly to, at any rate, the nearest two minutes

of arc. When further refinements have been introduced it is hoped to be able to better this considerably.

The operation of the instrument is simple. To plot planimetry once the photograph has been correctly oriented, the operator merely moves the index mark so that its image follows the outline of the feature on the photograph. The scale of the drawing is determined by the ratio between the height of the pinhole above the map and the height of the camera station above the ground. To intersect a point above the map datum level it is necessary to plot first the relative horizontal positions of the two photographs on a plotting sheet and the directions in which the camera was pointing at the moment of exposure. The first photograph is taken and correctly oriented, and the sheet is then oriented on the board so that the direction of the plotted camera axis points at right angles to the tilt axis and the position of the camera station lies directly under the pinhole. To facilitate the latter a centering device (16) has been provided. The image of the index mark is then made to superimpose the image of the point to be intersected, the pencil is placed in operation and a line drawn on the paper by moving the index mark in towards the operator. The same process is repeated with the second photograph and where the two lines intersect on the paper is the position of the point on the map. Then by placing the pencil at this intersection and lowering the tilt axis until the image of the index mark again covers the photographic image of the point the difference of height can be read directly on the height scale, the distance can also be read on the distance scale and the necessary correction to the height for curvature and refraction can be applied at once from tables.

The field of view of the periscope of the oblique plotter as constructed is sufficient to cover the field of a 7×9 inch photograph taken with a camera having a focal length of 10 inches but only in an up and down direction. It is not sufficient to cover it laterally. To do this without moving the eye while plotting, a simple optical linkage has been incorporated into the instrument and the following is a brief description of the geometry of this device.

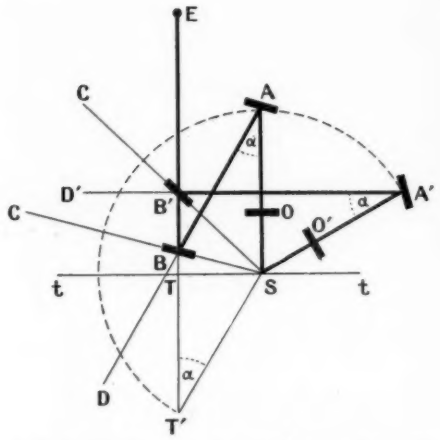

FIG. 6. Geometry of an optical linkage. A ray passing through the perspective center S and an objective O is always reflected by mirrors A and B into the optical axis of the eyepiece E and the length of the optical path remains constant, when the distance SA is made equal to ST cosec α and the plane of the mirror B contains S.

In Fig. 6 the paper represents a plane containing the tilt axis t–t and the optical axis of the periscope. The eyepiece of the periscope is fixed at E and its optical axis cuts the tilt axis at right angles at a distance ST from the pinhole S. Movable along the line ET is a rotatable mirror B whose plane is restrained always to point towards the pinhole S, by a rod SC which is free to slide parallel to the plane of the mirror through the rotatable mounting of B but is pivoted round a normal axis passing through S. Also rotatable around the axis at S is a rod SA on which is mounted the objective O of the periscope and a mirror A inclined so that the angle of reflection of the optical axis of the objective is α. The distance SA is made equal to ST cosec α. Rigidly attached to SA and making an angle α to it is another rod AD which is made to slide through the movable and rotatable mounting of B so that when B is moved along ET the rod DA causes the rod AS and consequently the objective O to swing round the pinhole.

With this arrangement for any position of the mirror B and for any pointing of the optical axis of the objective O the path of the optical axis of the latter will be reflected into the path of the optical axis of the eyepiece and the length

of the path between the pinhole S and the eye will be a constant.[4]

This can be proved as follows. In Fig. 6 let T' be the point on EBT produced where the latter is cut by a circle of radius SA centered at S. Make SA equal ST cosec α then the angle $BT'S$ must equal α. Now for any position of A such as A' the triangles $SA'B'$ and $ST'B'$ are similar, for by construction $B'S$ is common to both, SA' and ST' are equal and the angles $SA'B'$ and $ST'B'$ are equal. Thus the distance $EB'+B'A'+A'S$ must be constant because it always equals the constant distance $ET'+T'S$. Also because the angles $T'B'S$ and $A'B'S$ are equal, then by the ordinary laws of reflection, the ray from A' must be reflected at B' along the path $B'E$.[5]

In conclusion, it would seem reasonable to suggest that the principle of the pinhole mirror and real index mark should be applied to the construction of plotting instruments adapted for low obliques and verticals and in the construction of stereoscopic plotting and measuring instruments. It has the virtue of simplicity in that the accuracy of the plotting is not dependent on the precision of the mechanical movements which permit the viewing apparatus to scan the photographs and this, it may be added, is not true of the stereoscopic plotting instruments at present in use.[6]

It should also be noted that the pinhole mirror oblique plotter employs the reverse process to another type of photographic mapping instrument in which the image of the photograph is projected into a plane parallel to the map. In the latter type the optical problems of illumination and focus are more complicated than is the case of the pinhole mirror plotter in that it is a question of projecting an inclined plane surface rather than one point into a plane of reference.

[4] Such a device has other uses. For instance, by employing a pair of optical linkages, one for each eye, the field of view of a compound stereoscope may be traversed from side to side by the optical axes of the binocular objectives without moving the eyes or the photographs, thus enabling the observer to fuse stereoscopically homologous rays without eyestrain.

By employing a combination of two linkages for each eye the field of view of a stereoscope may be completely traversed by the optical axes of the binocular objectives both from side to side and up and down without moving the eyes or the photographs. Magnification of the field of view could then be introduced to any extent desirable. One other essential feature of the linkage is that the image, as seen by the observer, remains erect no matter in what direction the optical axis of the objective is pointing and this is accomplished without the use of a rotating "dove" prism.

[5] A further interesting geometrical property of this device, which can be deduced, is that the speed of rotation of the arm SA about S is always twice that of the arm SC.

[6] Reference 3, pp. 330–331.

The Thermoelectric Photometer of the Amherst College Observatory

WARREN K. GREEN, *Amherst College Observatory*

(Received March 1, 1935)

A thermoelectric photometer, designed and built at the Amherst College Observatory, is described. The instrument is much simpler and considerably less expensive than those which have been described by other authors. It contains a novel method for detecting and controlling variations in the intensity of the photometer lamp independently of the measuring galvanometer. Measures may be made more rapidly with this instrument than with the other types of thermoelectric photometers and the results are equally accurate.

THE plates taken at the Amherst College Observatory for the determination of photographic magnitudes of stars and asteroids are measured on a thermoelectric photometer designed and built here at Amherst. This instrument differs in many respects from the various modifications of the original Schilt[1] instrument which have been described elsewhere by Bennett,[2] Christie[3] and others. It is much simpler in design than the other instruments and the total cost of our instrument, including galvanometers and other accessories, is considerably less than one-half the quoted prices for any of the other instruments. The accuracy obtained with our instrument is at least as great as that obtained with any of the other thermoelectric instruments.

The plate to be measured, which is used in the horizontal position, is illuminated in the usual manner. An image of a condensing lens, illuminated by an incandescent lamp, is formed in the plane of the plate emulsion by a short focus microscope objective. The diameter of the condenser, and hence the area of the illuminated plate surface, is controlled by means of an iris diaphragm within the condenser.

The optical system of the measuring portions of the instrument is diagrammed in Fig. 1. The microscope objective O forms an image of the illuminated area of the plate on the thermopile T. A diaphragm, immediately in front of the thermopile receiver, is adjusted to the proper size to admit only the image of the illuminated area of the plate. At M is placed a piece of microscope cover glass, inclined at an angle of 22.5°, which deflects a portion of the light through the prism P to form an image of the illuminated plate area in the plane of the cross wires at C. The eyepiece E is focused on these cross wires. An opaque screen is placed at S which may be used to cut off the light from the thermopile when adjusting the zero point of the galvanometer. At F is a neutral filter to cut down the intensity of the image formed on the cross wires.

The tubes carrying the objective, thermopile and eyepiece are all screwed into a duralumin casting which also serves as a case for the deflecting mirror and prism, and the occulting

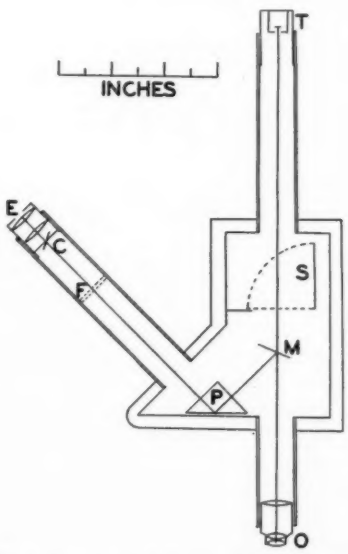

FIG. 1. Optical system of the measuring portion of the instrument.

[1] Schilt, Bulletin of the Astronomical Institutes of the Netherlands **2**, 135 (1924).

[2] Bennett, Astrophys. J. **78**, 305 (1933).

[3] Christie, Mt. Wilson Contr. No. 476; Astrophys. J. **78**, 313 (1933).

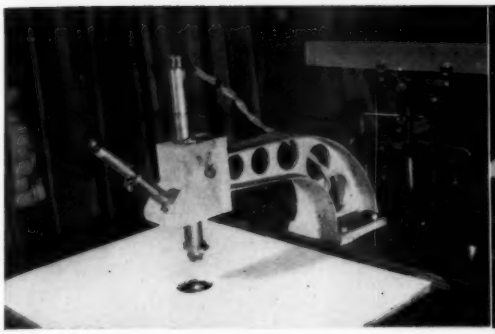

FIG. 2. The measuring portion of the Amherst photometer.

FIG. 3. The Amherst thermoelectric photometer.

screen. This casting is accurately faced with the top and bottom faces parallel, the back face perpendicular to the top and bottom, and the face for the eyepiece tube inclined at an angle of 45° to the top and bottom. To insure parallelism of the objective tube and the thermopile tube, the holes for these were bored and threaded in the casting at one operation in an accurate lathe. Any deviation of the eyepiece tube, either from the collimation plane of the objective-thermopile system or from proper inclination to the collimation axis, may be compensated for by adjustment of the prism *P*. This prism is attached to a small table which is carried on three pairs of push-pull screws which may be adjusted from outside of the case.

The case itself is attached through the back to a rigid arm which is attached to the frame of the table carrying the plate. As is shown in the photograph, Fig. 2, the objective-thermopile axis is held perpendicular to the plate.

The plate, film side up, is placed on a table with a 5-cm hole cut through it. A padded iron ring, weighing approximately 4 pounds, and with a 15-cm opening, is placed on the surface of the plate to hold it in contact with the flat surface of the plate table. The plate may be slid about on the table until the proper star image is within the field of view in the microscope *E*. The image is then centered on the cross wires by means of two perpendicular adjusting screws which may move the table through approximately 5 cm. These screws, at the front and right-hand side of the plate table, may be seen in the photograph of the complete instrument, Fig. 3. It is planned to adopt the customary manner of supporting the plate in a rigid frame just as soon as the money is available, permitting of orientation and two measured perpendicular motions. This will obviate the tedious process of marking each star image to be measured on a plate.

The measuring galvanometer is one designed by the Leeds and Northrup Company (their No. 2284-B) for use with a thermopile. It has a period of approximately 5 seconds with the proper damping resistance. The sensitivity of the measuring system is adjusted by means of the diaphragms in the condenser and in front of the thermopile. The diaphragm in the condenser is adjusted until the illuminated area of the plate is slightly larger than the area of the image of the brightest star to be measured on a given plate. Under such conditions a difference in deflection of approximately 80 mm is obtained between images of two stars differing in brightness by one stellar magnitude.

The deflections are read by the standard Leeds and Northrup method employing a spot of light on a ground glass scale. Such a method permits of easily reading deflections to 0.5 mm which, with our standard sensitivity, corresponds to a stellar magnitude difference of within 0.01 magnitude. The necessity for going to the expense and trouble of bringing the galvanometer scale into the field of view of the measuring microscope, as is done in the standard Schilt instrument[1,2] does not seem apparent to us. As is shown in the two photographs, the scale is so placed as to be directly in

front of the measurer as the eye is removed from the eyepiece. The measurer must take his eye from the eyepiece to record the deflection, and it is no added strain on the eye to glance up at the scale to read the deflection. Furthermore, the spot of light from the measuring galvanometer is before the eyes of the measurer, except when he is actually centering the star image, and any sudden drift of the galvanometer will be immediately noticed. The scale is arranged in the reverse direction so that when no light is falling on the thermopile, and the galvanometer is in proper adjustment, the scale reading is 500 mm. As light falls on the thermopile the scale reading diminishes. In measuring we adjust the current through the photometer lamp so that an area of plate free from star image will give a deflection of 500 mm, or a reading of 0 mm on the reversed scale. Then any reduction of radiation on the thermopile, as by bringing a star image into the path of the radiation, will produce a positive reading.

The current through the photometer lamp is controlled by means of the circuit diagrammed in Fig. 4. The resistances, except for the low resistance shunt, are designed by the Ohmite Company for use in radio circuits. They are designed to hold constant, within a very small range, for currents up to 12 amperes. Since we are using currents between 3 and 4 amperes they should be expected to hold constant during the measurement of a plate. The shunted resistance serves as a fine adjustment for the lamp intensity which can be controlled to within a value corresponding to less than 0.01 stellar magnitude difference. The voltmeter V is an inexpensive instrument used for the purpose of obtaining approximate values of the voltage applied to the lamp, and also to indicate the condition of the battery charge. The panel carrying the voltmeter and the two knobs for the variable resistances can be seen to the right rear of the table in Fig. 3. The lamp L is an ordinary 32 candlepower, single filament, automobile headlight bulb. The battery is made up of six heavy duty storage cells, arranged in two parallel groups of three cells in series. The battery is placed directly under the photometer, very heavy leads are used, and all connections are carefully soldered.

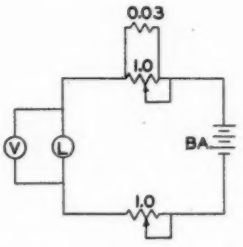

FIG. 4. The electric circuit for the photometer lamp.

In spite of all precautions it was found that there were fluctuations in the intensity of the photometer lamp. Numerous attempts were made to remove these fluctuations by increasing the sizes of the leads, by resoldering all connections, by eliminating variable resistances, etc., but fluctuations amounting at times to the equivalent of 0.2 stellar magnitude persisted. At times these fluctuations were very rapid and could be detected by simply glancing at the measuring galvanometer. At other times the more dangerous type of fluctuation, which produces a slow progressive drift of the galvanometer, was noted. The fluctuations may be due to polarization effects within the battery, but they do not appear to be correlated with the state of charge, except that when the battery has just been charged, or when the charge is very low, the fluctuations are very pronounced.

Since a sensitive control of the lamp intensity is at hand in the shunted resistance of the lamp circuit, all that was necessary to maintain constant intensity in the lamp while making a measurement was to design a method for detecting, independently of the measuring galvanometer, any slight variation in the intensity of the lamp. Fig. 5 shows a detection circuit which was designed and built by the Leeds and Northrup Company upon our suggestion. A Weston Electric Company photronic cell is placed about 20 cm from the photometer lamp and shielded from stray light by a tube 4 cm in diameter. A 100-ohm resistance is placed across this cell and the potential difference of the ends of this resistance is balanced through the slidewire W, potentiometer circuit shown, Fig. 5. All of the resistances and the slidewire are contained in a case similar to that used for the Leeds and Northrup No. 4261 student's slide-

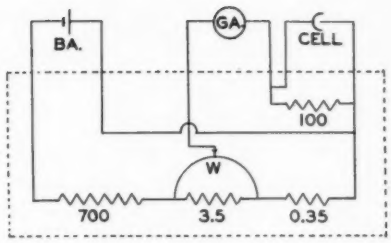

FIG. 5. Potentiometer control circuit for the photometer lamp.

wire potentiometer. The potentiometer case can be seen on the right front of the table in Fig. 3. The knife switch is for the purpose of short-circuiting the galvanometer when making large changes in the intensity of the photometer lamp. A diaphragm in the tube between the lamp and the photronic cell may be adjusted so that the potentiometer may be balanced for any value of the intensity of the photometer lamp which is to be encountered in the measurement of any series of plates.

The galvanometer used with the potentiometer is an inexpensive reflection type instrument. The spot of light from it is reflected to the same scale as that used for the measuring galvanometer and is colored green to distinguish it from the measuring spot. The sensitivity of the photronic cell potentiometer circuit is such that a variation in current through the photometer lamp sufficient to produce a deflection of 1.0 mm in the measuring galvanometer will produce a deflection of 10.0 mm in the potentiometer galvanometer. This is equivalent to saying that the circuit will detect a fluctuation in the photometer lamp which would introduce an error in measurement as small as 0.001 stellar magnitude. Since the spot of light from the potentiometer galvanometer is on the same ground glass scale as is the measuring galvanometer spot, the measurer has before him at all times a means for detecting the slightest variation in the intensity of the photometer lamp. In case such variation is noted, the current through the lamp can be adjusted to bring the potentiometer back into balance before the photometer reading is taken.

As is well known to all workers in the field of photographic photometry, the background of the plate, usually referred to as clear plate, is neither clear nor uniform in its fogging. Since the measurement of the brightness of a star by the thermoelectric method involves the relative blackening of the film by the star image, any variations in the fogging of the clear plate in the immediate vicinity of the star image will introduce errors. Such errors are referred to as plate errors. The fogging of the clear plate may change very appreciably within a few millimeters of plate surface[4] and it is impossible, in practice, to obtain a clear plate reading for each star to be measured. The usual procedure[5] is to select some area on the plate, assumed to be free from a star image, and adjust the current through the lamp until some standard deflection is obtained. This deflection is then subtracted from each deflection obtained with a star image in the field and the difference is taken as that due to the star image alone. Any difference in plate background between the region in the immediate vicinity of the star image and the standard area is neglected and appears in the results of the measures on the star images as plate error. For the purpose of checking the constancy of the photometer lamp, frequent returns to the standard area must be made during the measurement of the plate.

With the Amherst photometer these returns to a standard area are not necessary. A spot on the plate, assumed free from a star image, is selected and the current through the lamp is adjusted until a full scale deflection, 0-mm reading, is obtained. The potentiometer is then balanced and the lamp intensity maintained constant during the measurement of the star images on the plate by adjustment of the current through the lamp.

It is, of course, necessary to cut off the light from the thermopile occasionally to check the zero deflection, 500-mm reading, of the galvanometer. It has been found with our instrument, which is located in a room maintained at practically constant temperature and free from air currents, the zero deflection remains remarkably constant. A variation greater than 5 mm has never been found during the measurement of a plate.

[4] J. T. Lay and I. C. Cornog, J. Opt. Soc. Am. **24**, 149 (1934).

[5] G. R. Harrison, J. Opt. Soc. Am. **19**, 268 (1929).

The control of the lamp circuit, independently of the measuring galvanometer, provides a method for the determination of the magnitude of the plate error. A section of clear plate is arbitrarily chosen and the current through the lamp adjusted until a reading of approximately 50 mm is obtained on the measuring galvanometer scale. Then, holding the lamp intensity constant, a series of twenty readings is taken on sections of clear plate scattered uniformly through the field of stars to be measured. The probable error of the mean of these readings will be a measure of the irregularity in the density of the plate background or, in other words, will be a measure of the plate error.

A detailed discussion of a long series of measures made with the Amherst photometer will be published later. A brief summary of results obtained from measures of about 50 plates will be of interest. Our plates are taken on Eastman 50 emulsion at the focus of a Ross-Lundin lens of 4.5-inch aperture. These plates are developed in developer D–11 at 20°C for 6 minutes. From the readings taken on clear plate areas we find that the plate error averages ± 0.040 stellar magnitude. The probable error of a single magnitude determination made with the photometer averages ± 0.041 stellar magnitude. The close agreement of this value with that obtained for the plate error indicates that the photometer gives the best results obtainable from plates taken under our observing conditions. Our accuracy compares favorably with results obtained with other forms of thermo-electric photometers, other published values for the probable error of a single magnitude determination being: Schilt[1] ± 0.05, Schilt[6] ± 0.08, and A. deSitter[7] ± 0.07. The slight increase in accuracy is apparently due to the independent control of the lamp intensity. Before this control was installed we made a number of measures in the standard manner, i.e., returning to a standard area between star measures, and obtained as a probable error of a single determination ± 0.07 magnitude.

In addition to increasing the accuracy of the instrument, the potentiometer control of the lamp intensity saves considerable time in the measurement of a plate since it obviates the necessity of making frequent returns to a standard clear plate area. We estimate the saving of time to amount to at least 25 percent.

Acknowledgment is made to Mr. T. G. Mehlin, who did much of the designing and mechanical work in connection with the construction of the measuring head of the instrument. The Leeds and Northrup company were very helpful in the design and construction of the potentiometer circuit.

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[6] Schilt, Trans. Astro. Obs. Yale University **9**, 30 (1933).
[7] A. deSitter, Bull. Astro. Inst. Netherlands **6**, 65 (1932).

A Heliostat for the Physics Laboratory

ARTHUR ADEL, *University of Michigan*

(Received March 2, 1935)

IN an investigation of the remote infrared telluric spectrum, recently conducted at the University of Michigan,[1] we found it most practicable to design and construct our own heliostat. The inadequacy of heliostats commonly used in physics laboratories is primarily the result of small size and delicacy of construction. Moreover, in this research the distance from heliostat to focus was more than 100 feet. This necessitated high precision in the drive to keep the image of the sun on the slit of the spectrometer for about two hours.

The heliostat to be described, is simple, and satisfies the demands of adequate size, mechanical strength and accurate timing.

Fig. 1 shows the instrument in operation. The first mirror, mounted on an equatorial axis, is driven 15° per hour through a reducing unit by a small synchronous motor. The adjustment for daily change in declination of the sun may be identified in the photograph by the counterweight suspended from it. When both mirrors are properly adjusted the sunlight strikes the first mirror, is reflected parallel to the axis of rotation of this mirror to the second mirror, thence through a ten-inch opening in the supporting platform directly below the second mirror, and downward four floors to the level of the second basement. Here the light is reflected into a spectrometer room.

Both mirrors are made from good quality of plate glass, nine inches in diameter, and front-silvered by evaporation. When not in use the second mirror is removed from the platform and the first mirror from the driving shaft. A specially made metal cover is then used to protect the remaining apparatus against weather. A view of the covered heliostat mounted on its supporting platform is shown in Fig. 2.

[1] A. Adel, V. M. Slipher and E. F. Barker, Phys. Rev. **47**, 580 (1935).

FIG. 1.

FIG. 2.

Journal of the Optical Society of America

STATEMENT OF OPERATIONS FOR THE YEAR ENDING DECEMBER 31, 1934
Account at the American Institute of Physics, New York City

Income collected by the Institute for the Optical Society of America

Subscriptions		$3,244.39	
Other Income:			
Sale of reprints	$282.00		
Sale of single copies	197.05		
"Per page charge" income	975.00	1,454.05	
Total income collected			$4,698.44

Expenses chargeable to the *Journal of the Optical Society of America*

Balance due American Institute of Physics from 1933 account		$ 120.11	
Printing and Mailing Cost		3,409.88	
Editorial Expenses:			
Salaries	$540.57		
Rent	62.28		
Stationery, Printing and Supplies	20.67		
Postage	49.39		
Telephone and Telegraph	14.10		
Miscellaneous	4.85	691.86	
Business Management Expenses:			
Salaries	650.31		
Rent	74.88		
Stationery, Printing and Supplies	34.16		
Postage	61.10		
Telephone and Telegraph	12.79		
Miscellaneous	71.03	904.27	
Reprint Cost		407.33	
"Institute" Service Charge		812.00	
			$6,345.45
Net operating expense, payable to American Institute of Physics (includes $120.11 from 1933 operations)			$1,647.01
Cash received from the Treasurer of the Optical Society of America; from the sale of back numbers and from miscellaneous sources			$1,766.11
Due to the Optical Society of America, December 31, 1934			119.10

Account in the Editorial Office, Ithaca, N. Y.

Postage	$ 42.05	
Office expense	46.94	
Draftsman	14.10	
Salaries	800.00	903.09
Net cost to the Society of the *Journal of the Optical Society of America* for 1934		$2,429.99

F. K. RICHTMYER, *Editor*

Proceedings of the New York Meeting of the Optical Society of America

FEBRUARY 22 AND 23, 1935

JOINT MEETING WITH THE AMERICAN PHYSICAL SOCIETY

THE joint meeting of the Optical Society of America and the American Physical Society was held in New York City, February 22 and 23, 1935.

JOINT SYMPOSIUM ON ATMOSPHERIC OPTICS

The principal feature of the meeting was the joint symposium of the two Societies on Friday morning, February 22, devoted to invited papers on *Atmospheric Optics*. The following papers were presented:

1. **Introduction.** BRIAN O'BRIEN, *Institute of Applied Optics, University of Rochester*
2. **The Geometrical Theory of Halos.** EDGAR W. WOOLARD, *U. S. Weather Bureau*
3. **Astronomical Seeing.** J. A. ANDERSON, *Mt. Wilson Observatory*
4. **Distribution of Atmospheric Ozone.** R. LADENBURG, *Princeton University*
5. **Light Absorption in the Atmosphere and its Photo-Chemistry.** OLIVER R. WULF, *Bureau of Chemistry and Soils*

INVITED PAPERS ON ATMOSPHERIC OPTICS

On Friday afternoon the following invited papers on *Atmospheric Optics* were presented:

6. **Scattering of Light by Atmospheric Particles.** J. A. STRATTON, *Massachusetts Institute of Technology*
7. **Attenuation of Light in the Lower Atmosphere.** E. O. HULBURT, *Naval Research Laboratory*
8. **Visibility of Signals Through Fog.** GJON MILI, *Westinghouse Lamp Company*
9. **Atmospheric Optics in Aviation Lighting.** F. C. BRECKENRIDGE, *National Bureau of Standards*

JOINT DINNER

On Friday evening, February 22, a joint dinner for the members of the two Societies was held, with Professor R. W. Wood, president of the Physical Society, presiding.

PUBLIC LECTURE ON "THE OPTICAL PHENOMENA OF CLOUDS"

Following the dinner Dr. W. J. Humphreys of the United States Weather Bureau gave by invitation a public lecture on "The Optical Phenomena of Clouds."

CONTRIBUTED PAPERS

Simultaneous meetings of the American Physical Society and the Optical Society of America for the reading of contributed papers were held on Saturday, February 23. The authors' abstracts of the papers presented before the Optical Society are appended.

MEETING OF THE BOARD OF DIRECTORS

A meeting of the Board of Directors was held Thursday afternoon and evening, February 21. Minutes of this meeting are appended.

L. B. TUCKERMAN, *Secretary*

Minutes of the Fifth Meeting of the Directors of the Optical Society of America, Incorporated

NEW YORK, NEW YORK, FEBRUARY 21, 1935

BESIDES the transaction of routine business the following items of general interest to members of the Society were taken up:

The following appointments and nominations were announced:

Glossary Committee
I. C. Gardner, *Chairman* J. S. Friedenwald
Roger S. Estey Rudolph Kingslake
Henry F. Kurtz

Committee on Honorary Members
W. E. Forsythe, *Chairman* F. E. Wright
R. C. Gibbs

Committee on Award of Ives Medal
K. K. Darrow, *Chairman* G. W. Moffitt
A. C. Hardy H. P. Gage
T. R. Wilkins

Committee to consider resolutions supporting Science Advisory Board
C. L. Bausch L. A. Jones
F. K. Richtmyer

Committee to prepare text for Optical Society Directory
H. E. Ives, *Chairman* L. B. Tuckerman
Nominating Committee
E. C. Crittenden, *Chairman* P. I. Wold
J. P. C. Southall R. T. Birge
R. B. Wilsey
Committee on Index for Journal
F. K. Richtmyer, *Chairman* R. C. Gibbs
A. C. Hardy
Nomination
Director of the American Institute of Physics
F. K. Richtmyer for a term beginning February, 1935 and expiring February, 1938 (elected at meeting of A. I. P. February 21, 1935).
Chairman of Membership Committee
T. R. Wilkins

Treasurer's Report

The Treasurer presented the Annual Report for the fiscal year 1934 audited by Carl L. Bausch and C. W. Frederick. Accompanying the report was an informal discussion of the financial status of the Society, showing that the finances of the Society were in good condition. This favorable financial condition was in large measure to be ascribed to the efficiency of the American Institute of Physics in handling the publication at low cost.

Cumulative Index

It was voted that a cumulative index of the Journal be published to cover all numbers up to and including the issue of December, 1934.

Motion Picture Sectional Committee

It was voted that the Society accept the invitation to appoint a representative on the Motion Picture Sectional Committee.

Ives Medal

It was noted that although the endowment of this medal by Herbert E. Ives and the terms of the endowment had been accepted by the Executive Council of the Society at its meeting in New York City, February 24, 1928, the conditions of the endowment had not been entered upon the official records of the Society since its incorporation.

The Secretary then laid before the Directors the terms of the endowment as follows:

1. The donor gives to the Optical Society of America the sum of $1000.00 to be used to found and endow "The Frederic Ives Medal."

2. Of this sum, not more than $500.00 shall be expended in the preparation of the dies of a design to be acceptable to both the donor and the Optical Society

3. The money remaining after the preparation of the dies shall be invested by the Optical Society and the interest therefrom shall be used to pay for the striking of a medal, not oftener than once every two years.

4. The medal shall be struck in silver until such time as the principal of the fund shall attain a value by accumulated interest or otherwise such that the income therefrom shall permit striking the medal in gold.

5. The medal shall be awarded by the Optical Society for distinguished work in optics. While there shall be no rigid restrictions as to the nationality of the recipient or the nature of the achievement it is desired to recognize, it is the preference of the donor that the medal be primarily an award for American workers, in the fields which it is the purpose of the Optical Society to foster.

6. Any excess of income from the fund beyond the amount necessary for the striking of the medal in gold shall be used by the Society to aid in the maintenance of its *Journal.*

It was voted that the Directors of the Optical Society of America, Incorporated, reaffirm the acceptance of the terms of the endowment of the Frederic Ives Medal and instruct the secretary to publish them in the J. O. S. A.

American Standards Association

The Directors voted that the President write to the American Standards Association suggesting that the Optical Society of America would be glad to cooperate in the work of the Association's committee to formulate specifications for safety glass for automobiles.

Program of Sessions for Contributed Papers

(TITLES AND ABSTRACTS* OF PAPERS)

10. Estimation of Chromaticity Differences and Nearest Color Temperature on the Standard 1931 I.C.I. Colorimetric Coordinate System. DEANE B. JUDD, *National Bureau of Standards.* (10 minutes.)

A Maxwell triangle yielding uniform chromaticity scales has been derived[1] by a trial-and-error method from comparison with experimental data on chromaticity sensibility. On this triangle the length of any line is a close measure of the chromaticity difference between the stimuli represented at the extremes of the line. To show the relative distortion between the uniform-chromaticity-scale triangle and the standard 1931 I.C.I. colorimetric coordinate system,[2] a group of thirty equal tangent circles on the former triangle have been transferred to the standard system where they appear as ellipses of various sizes, eccentricities, and orientations. A plot of these ellipses on the (x, y)-plot of the standard system assists in the estimation of chromaticity differences from trilinear coordinates on the standard system.

On the uniform-chromaticity-scale triangle the method for estimating nearest color temperature for a neighboring non-Planckian color stimulus is to draw the normal to the Planckian locus through the point representing the neighboring stimulus. The intersection of this normal with the Planckian locus gives the best estimate so far as possible of the nearest color temperature. To facilitate carrying out this estimate on the standard coordinate system, a large number of the normals on the equal-chromaticity-scale triangle have been transferred to the standard system where they are, of course, no longer normal to the Planckian locus. These transferred normals drawn on the (x, y)-plot of the standard colorimetric coordinate system permit nearest color temperature to be read directly from the trilinear coordinates of the non-Planckian stimulus without the intermediate step of transforming these coordinates to the equal-chromaticity-scale system. Values of nearest color temperature by this method agree well with correlated color temperature by the Davis method[3] up to 3000°K but depart somewhat at higher temperatures.

[1] Judd, *A Maxwell Triangle Yielding Uniform Chromaticity Scales*, J. O. S. A. **24**, 163 (1934).
[2] Judd, *The 1931 I. C. I. Standard Observer and Coordinate System for Colorimetry*, J. O. S. A. **23**, 359 (1933).
[3] Davis, *A Correlated Color Temperature for Illuminants*, Bur. Standards J. Research **7**, 659 (1931).

11. Maximum Visual Reflectance of a Surface Having a Given Chromaticity. DAVID L. MACADAM, *Massachusetts Institute of Technology.* (10 minutes.)

Any reflecting surface is characterized by a spectral reflectance curve, the values of reflectance lying between 0 percent and 100 percent. From the spectral reflectance curve, it is possible to compute the dominant wavelength, purity and relative brightness for a given source and observer. In this paper an investigation has been made of the maximum brightness that is possible for a given dominant wavelength and purity, assuming Illuminant C and the I.C.I. observer. By plotting maximum brightness vertically from each point in the I.C.I. triangle, a surface is secured which bounds a volume containing all the colors that are obtainable on a reflecting surface. This may be regarded as the color solid inherent in the I.C.I. data and does not depend upon the pigments that are available at present.

12. Critical Fusion Frequency in Different Spectral Regions. SELIG HECHT AND SIMON SHLAER, *Columbia University.* (20 minutes.)

In continuing our flicker investigations, we have improved the optical system so as to yield (a) a maximum brightness of 100,000 millilamberts, (b) a measuring field of 40° diameter, and (c) a fixation point of easily variable intensity and position.

Our previous measurements showed that the relation of critical frequency to intensity falls into two clearly divisible sections: a low intensity one, in which the critical frequency increases with intensity and reaches a maximum, maintained as a plateau, and following this a high region which also varies with intensity. The tentative identification of these sections as representing rod and cone functions, respectively, is now confirmed by measurements with different parts of the spectrum.

Using a 19° flickering area, centrally fixated, and surrounded by a non-flickering field 40° in diameter, we find that going from blue to red the cone portion remains essentially the same for all colors. The rod portion, however, suffers two changes. First, the extent of the intensity range decreases from four and a half log units in the blue to less than one log unit in the red, a reduction of 1000 to 1. This change in intensity range for different parts of the spectrum is easily understandable in terms of the photochromatic interval. Second, the maximum plateau value of the fusion frequency varies with λ. The plateau is highest (14.5 cycles per second) for the green; it decreases slightly toward the blue (12.6), and sharply to the yellow (11.5) and to the red (7.9).

This change of the maximum suggests a specific effect of λ as opposed to a mere difference in absorption such as would be expected with a single photosensitive substance like visual purple, in which all wavelengths presumably produce the same effect provided their intensities are large enough. Judged by sensation alone, the effect here is colorless and identical for all λ values; judged by critical fusion frequency, each portion of the spectrum produces a different effect.

The present paper will appear in full in the Journal of General Physiology.

13. Area and Critical Fusion Frequency of Flicker. SELIG HECHT AND EMIL L. SMITH, *Columbia University.* (25 minutes.)

* The abstracts were preprinted in the program subject to correction by the authors. Corrections that have been communicated to the secretary have been made in the abstracts here reprinted.

In previous work on the influence of area on critical frequency of flicker, the measuring area corresponded to the total illuminated area on the retina. We have measured the influence of measuring area when the total illuminated area was constant at a diameter of 40°. Increasing area from 0.3° to 19.0° produces different effects on the low and on the high intensity portions. The extent of the low intensity portion increases from nothing up to 2° until it covers 3.75 log units at 19°, where most of it is plateau. Since this corresponds anatomically with the distribution of rods, this confirms the identification of the low intensity portion with rod function. The plateau maximum also increases with area.

The high intensity portion changes little with area. For S.H. it remains essentially constant, the maximum frequency varying haphazardly between 47 and 52. For E.L.S. the maximum increases with area. From 0.3° to 6.0°, an increase in area of 1 to 400, the maximum goes from 40 to 45 cycles per second; at 19° it is 58. The presence or absence of the correlation with area probably depends on the criterion for judging flicker disappearance. This influences the maximum, but not the shape of the curve.

A theoretical relationship between frequency and intensity appears in terms of concentration of photosensitive substance and products at the stationary state. The relations differ critically with the order of the light and dark reactions. For the rod data critical frequency is proportional directly to the photo-product concentration when both light and dark reactions are monomolecular, or to the square of the concentration when the light reaction is monomolecular and the dark bimolecular. For the cones the data show a proportionality between critical frequency and concentration when both light and dark reactions are bimolecular.

In the cone portion, indications appear of a possible double relationship between flicker and intensity. This is not due to an admixture of rods in the cone portion, because it shows in the smallest fields and cannot be separated out by using extremes of red and blue light.

The present paper will appear in full in the Journal of General Physiology.

14. Disk Colorimetry Information. DOROTHY NICKERSON, *Bureau of Agricultural Economics.* (10 minutes.)

For careful work with the disk method of colorimetry, one must have (1) information concerning the color temperature of illumination and (2) careful measurements of the papers used as standards with the instruments. The purpose of this paper is to provide a certain amount of information on each of these subjects.

(1) Color temperatures are given for lamp and filter combinations of available instruments.

(2) The notation of the Munsell system is useful in color specification. More information must be made available if the papers are to serve their full purpose. Various formulas, surrounded by appropriate precautions, developed and used for specific purposes will serve a useful purpose until such time as information is assembled to provide more accurate tables, charts, or formulas for conversion of disk areas to equally stepped scales of hue, brilliance and saturation. (The basis for such work has recently been completed in Professor Hardy's laboratory in spectral reflectance measurements for all of the Munsell colors.)

Meanwhile, it has been necessary to standardize certain Munsell colors. Tristimulus specifications for several Munsell papers under I.C.I. standard illuminants have been calculated from spectral reflectance measurements made at the National Bureau of Standards. In order to compare the order of difference due to different methods of computation, and the order of difference due to curves somewhat similar in spectral reflectance, with the order of difference important in color grading work, tristimulus computations have been made and are presented for purposes of comparison. Specifications are given for certain glossy papers under diffuse and 45° directional illumination. Specifications are given for colors made in the Munsell laboratory to match other colors, using different pigments.

The present paper will appear in full in the Journal of the Optical Society.

15. Photographic Plates for Use in Spectroscopy and Astronomy, IV. C. E. KENNETH MEES, *Eastman Kodak Company.* (15 minutes.)

In addition to the types of emulsion used for spectroscopic plates, a new type has been made which, when sensitized for the infrared, has as much sensitivity as the Type I emulsion but shows a contrast and graininess corresponding to Type IV. In connection with this, a new nomenclature is introduced and the emulsion is termed Type 144.

As a result of a great advance in the production of polycarbocyanine dyes, it has been possible to revise and extend the sensitizing for the infrared.

A new sensitizing, Type M, has been introduced giving a maximum of sensitivity at λ9300, and a pentacarbocyanine dye has been obtained which gives a maximum of sensitivity at λ10,900. Plates made with this dye, which are known as Type Z, enable the infrared to be photographed at least as far as λ12,000.

The present paper will appear in full in the Journal of the Optical Society; C. E. Kenneth Mees, J. Opt. Soc. Am. **21**, 753 (1931); **22**, 204 (1932); **23**, 229 (1933).

16. Anomalous Dispersion Within Absorption Bands. A. H. PFUND, *Johns Hopkins University.* (10 minutes.)

Because of the great weakening of light, it is usually difficult to follow the dispersion of a substance through an absorption band. In previous work (Pfund, J. O. S. A. **24**, 121 (1934)) it has been shown that, by making use of diffraction bands, dispersion may be followed through an absorption band: the necessary condition for the production of sharp bands being that the intensity of the beam falling on the absorbing medium be sufficiently increased over that of the "other" beam that their intensities, upon interference, be the same. This principle is here applied to a Young's interference apparatus by means of which the dispersion of aniline violet, neodymium nitrate and gold is readily followed through the regions of absorption. It is shown that the above outlined procedure may be readily applied to the Michelson interferometer.

The present paper will appear in full in the Journal of the Optical Society.

17. Change in the Photoelectric Threshold of Thorium and Similar Metals by Oxygen. H. C. RENTSCHLER AND D. E. HENRY, *Westinghouse Lamp Company, Bloomfield, N. J.* (10 minutes.)

The use of silver oxide for producing caesium photoelectric cells of increased sensitivity is commonly known. Barium cells are generally prepared from barium oxide surfaces. An experiment will be described which shows that when a small amount of oxygen is introduced into a photo-cell with a clean surface of thorium the sensitivity is increased and the threshold is shifted towards the longer wavelength. This result is of importance in indicating the nature of the photo-active surface of these metals.

The present paper will appear in full in the Journal of the Optical Society.

18. A Photoelectric Colorimeter with Logarithmic Response. RALPH H. MÜLLER AND GILBERT F. KINNEY, *New York University.* (10 minutes.)

The photometric measurement of colored solutions which obey Beer's law is most conveniently represented by a semilogarithmic plot of transmittancy against concentration. This is always preferable to purely empirical calibration.[1] It is highly desirable, however, to have an instrument which is direct reading. Since the light intensity varies logarithmically with concentration, the photoelectric current can be fed into a vacuum-tube voltmeter having a logarithmic input characteristic. The plate current will then be a linear function of the concentration. This type of vacuum-tube voltmeter has been used extensively in the communication field.[2]

In applying it to colorimetry the conventional methods had to be modified somewhat. An RCA Type 6D6 tube is employed with a suitable biasing resistor in the cathode lead. Under the chosen conditions of operation a value for this resistor can be found which will yield a plate current varying as the logarithm of the input voltage over a limited but adequate range. This relationship never extends to zero plate current. For this reason it is necessary to balance out a portion of the plate current, giving, in effect, a suppressed-zero instrument. Advantage is taken of the suppressed-zero feature by using a sensitive meter in the plate circuit. The range of the photometer is extended by a choice of input resistors and the use of a multi-range meter in the plate circuit. The scales can be calibrated directly in concentration units. For automatic recording, as, for example, in following the course of rapid reactions, the direct reading feature is of distinct value.

The same result can be achieved in other ways. The open-circuit e.m.f. of a barrier-layer cell is a logarithmic function of the light intensity and can be employed in colorimetry.

The present paper will appear in full in the Review of Scientific Instruments.

[1] R. H. Müller, Mikrochemie **11**, 353 (1932).
[2] S. Ballentine, Electronics **1**, 472 (1931); J. Acous. Soc. Am. **5**, 10 (1933); F. V. Hunt, R. S. I. **4**, 672 (1934).

19. A Direct Reading Comparator for Spectra. L. G. HOXTON, *University of Virginia,* AND D. W. MANN, *Harvard University.* (20 minutes.)

This instrument is capable of reading off directly from the lines of a spectrogram to the divided head of a screw either wavelengths or wave-frequency numbers as desired. The degree of approximation is closer than that yielded by the Hartmann interpolation formula.

In effect the Hartmann formula is first mechanically realized through a principle of geometric projection, but by introducing an element of eccentricity with respect to the point of projection, the equivalent of a fourth constant in the formula is added. The instrument may then be adjusted to four known lines on the plate instead of three as would be the case in dealing with the formula.

One moving part, on an accurate pivot, consisting of two adjustable arms with straight edges, is interposed between the screw carriage and the plate carriage and, pressing against steel balls fixed to the two carriages, constitutes the transfer mechanism from screw to plate.

An example of the instrument will be shown. It was developed from a crude model described before the Society in 1929[1] and was built by the Mann Instrument Company of Cambridge, Massachusetts.

[1] L. G. Hoxton, J. O. S. A. and R. S. I. **18**, 443 (1929).

20. An Optical Device to Aid in Mapping from Photographs. O. M. MILLER, *American Geographical Society.* (15 minutes.)

The paper describes an optical device invented by the author to aid in the plotting of maps from photographs. It is the development of an idea first suggested by Deville[1] whereby an observer views directly through a half-silvered mirror an index mark attached to a plotting pencil moving in the plane of the map and views by reflection from the mirror the photographic view set at its correct orientation to the map plane. An image of the real index mark is thus seen superimposed in the perspective view. This simple device is not practical in a precision instrument, due principally to the difficulty of keeping the moving index mark in focus to the observer while he is concentrating on details in the picture plane. The device as developed by the author succeeds in overcoming this difficulty of focus by the use of a pinhole mirror and a periscope. Thin pencils of rays from an illuminated moving index mark behind the mirror on passing through the pinhole are enveloped by corresponding reflected pencils from point images in the photograph. The periscope functions solely as a viewing apparatus whereby the eye is placed virtually at the perspective center of the set-up, namely, the pinhole.

An instrument for plotting planimetry from single oblique aerial photographs, which incorporates this device, is in use at the American Geographical Society, and the author hopes eventually to build a stereoscopic plotting machine on the same principle.

[1] E. Deville, *On the Use of the Wheatstone Stereoscope in Photographic Surveying,* Trans. Roy. Soc. Canada **8**, 63–69 (1902). Also O. von Gruber, *Photogrammetry: Collected Lectures and Essays,* translated from the German original by G. T. McCaw and F. A. Cazalet, American Photographic Publishing Company, Boston, 1932.

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